# Kentucky Wastewater Collection System Operator Certification Examination Review Manual

COMMONWEALTH OF KENTUCKY
ENERGY AND ENVIRONMENT CABINET
DIVISION OF COMPLIANCE ASSISTANCE
CERTIFICATION AND LICENSING PROGRAM

Kentucky Board of Certification of
Wastewater System Operators

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**Information contained in this manual was collected and compiled from several resources and federal documents.**

**Compiled by Timothy P. Ricketts**

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## WASTEWATER CHARACTERISTICS

Total solids make up approximately **0.1 percent** of the total composition of domestic wastewater (700 – 1000 ppm)**.** Total solids are composed of suspended and dissolved solids with colloidal solids making up a portion of both. Dissolved solids (400 – 700 ppm) consist of both organic and inorganic molecules and ions that are present in true solution in water (sulfates, chlorides, etc.). A certain level of these minerals in water is necessary for aquatic life. Changes in total dissolved solids concentrations can be harmful because the density of the water determines the flow of water into and out of an organism's cells.

The colloidal fractions are very small solids that cannot be removed by physical settling. **Total suspended solids (180 – 300 ppm)** are the solids captured on the special filter when performing the TSS test, as specified by Standard Methods for the Examination of Water and Wastewater. Suspended solids can be further divided into settleable and colloidal solids where settleable solids are those solids that will settle to the bottom of an Imhoff cone in a 60-minute period and are normally removed by primary sedimentation.

Approximately 70 percent of the suspended solids and 40 percent of the dissolved solids are organic in nature. This leaves 30 percent of the suspended and 60 percent of the dissolved solids that are inorganic. These solids are made up of minerals, such as carbonate, sulfate, phosphate, nitrate, calcium, magnesium, sodium and others. The bacterial process does not affect these types of material, and most of it passes through the plant and is discharged unchanged. Some of these minerals may be removed through chemical precipitation.

The biochemical oxygen demand, ($BOD_5$), is a measure of the organic strength of wastewater. In domestic wastewater, it has a **range of 160 – 280 mg/L.** The test can be roughly defined as a measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. It is also a measure of the quantity of dissolved organic pollutants that can be removed in biological oxidation by the bacteria. It is expressed in mg/L of oxygen**.** Some of the $BOD_5$ (organic material) that is degraded is utilized by the bacteria in the production of new bacteria cells. The $BOD_5$ test only measures the $BOD_5$ (organic material) that is oxidized in bacterial respiration, so it does not measure the carbon used for cell growth.

Total Kjeldahl Nitrogen is the sum of the organic nitrogen and ammonia-nitrogen. Normal ranges for domestic wastewater are **Kjeldahl nitrogen (40–50 ppm), organic nitrogen (15–20 ppm), and ammonia-nitrogen (25–30 ppm).** Most of the nitrogen in influent is from animal and plant protein. Total organic nitrogen is a measure of protein and the intermediate decomposition products. Nitrogen as ammonia indicates progress in the breakdown of nitrogenous compounds. Oxygen is constantly entering and leaving water, but there is a certain amount of oxygen in water at all times. This is because water has a natural attraction to oxygen. When oxygen comes in contact with the surface of water, the oxygen tends to enter the water, becoming dissolved oxygen.

The amount of attraction between oxygen and water depends on the amount of oxygen already in the water. If there is very little oxygen in water, then the water is very attractive to oxygen. But when water has a high concentration of DO, then the water is **saturated**, meaning that the water contains as much oxygen as it can hold at that temperature. Saturated water is not very attractive to oxygen.

The process of oxygen moving from an area with a high oxygen concentration to an area with a low oxygen concentration is known as **diffusion.** Water temperature is very important in determining the amount of oxygen that will become dissolved in water. Cold water is able to hold more oxygen than warm water.

Water, the home of most bacteria, contains oxygen in two forms. The first form, **free oxygen**, is the most readily available form. Free oxygen is basically the same as dissolved oxygen—oxygen from the atmosphere that has become dissolved in water. **Aerobic bacteria** require free oxygen in order to survive.

Oxygen can also be found in the water in another form. Food and even water itself contain oxygen, but this oxygen is tightly bound to the food and water. However, the oxygen can be ripped out of the water molecule by **anaerobic bacteria**, but it takes much more energy to break apart food and water in search of oxygen than it does to simply use free oxygen. Since anaerobic bacteria use so much of their time and energy scrounging for oxygen, they take longer to digest organic matter in water. Anaerobic bacteria are the major cause of hydrogen sulfide production in the collection system. Through anaerobic respiration, sulfur-reducing bacteria produce Hydrogen sulfide gas ($H_2S$), which is an inhalation hazard and causes corrosion of collection system equipment.

The third type of microorganisms, those which are **facultative**, have properties of both aerobic and anaerobic organisms. They can live with or without free oxygen. When the oxygen content of water is high, facultative bacteria consume food very quickly using the free oxygen in the water. In low oxygen concentrations, facultative bacteria are still able to consume organic material, although they do so much more slowly.

**Biological treatment – design & operational considerations**

Population equivalents that are used to calculate hydraulic and organic loadings for domestic wastewater treatment if actual operating information is not available are as follows:

| | |
|---|---|
| **$BOD_5$** | **= 0.17 lbs./capita/day** |
| **TSS** | **= 0.20 lbs./capita/day** |
| **Phosphorus** | **= 0.0048 lbs/capita/day** |
| **Flow** | **= 100 gallons/capita/day** |

Ideal nutrient requirements for biological stabilization of organic matter result in following ratio:

**Carbon/Nitrogen/Phosphorus = C/N/P = 100/5/1**

Another way of viewing this nutrient balance is to consider the $BOD_5$ as the carbon source so that for every 100 ppm of $BOD_5$ removed, there would have to be 5 ppm of nitrogen and 1 ppm of phosphorus available for cell synthesis. The units of measure, if the same, do not matter because it is the ratio that is important.

## PIPES

### Definitions
Crown—inside top of pipe
Invert—the lowest point of the inside of a pipe or manhole
Force main—a pipe that carries wastewater under pressure from the discharge side of the pump

### Pipe construction and materials
There are several different pipe materials available for wastewater collection systems, each with a unique characteristic used in different conditions. The four different pipe materials described below are:

- ductile iron,
- concrete,
- plastic, and
- vitrified clay.

Pipe material selection considerations include:

- trench conditions (geologic conditions),
- corrosion,
- temperature,
- safety requirements, and
- cost.

Key pipe characteristics areas follow:

- corrosion resistance (interior and exterior),
- scouring factor,
- leak tightness, and
- hydraulic characteristics.

Pipe manufacturers follow requirements set by the American Society of Testing Materials (ASTM) or American Water Works Association (AWWA) for specific pipe materials. Specification standards cover the manufacture of pipes and specify parameters, such as:

- internal diameter,
- loadings (classes), and
- wall thickness (schedule).

The methods of pipe construction vary greatly with the pipe materials. Some new pipe materials and construction methods use the basic materials of concrete pipes with modifications (i.e., coatings). Other pipe manufacturing methods use newly developed resins, which offer improvements in strength, flexibility and resistance to certain chemicals. Construction methods may also allow for field modifications to adapt to unique conditions (i.e., river crossings, rocky trenches, etc.) or may allow for special, custom-ordered diameters and lengths.

**Ductile iron pipe**

Ductile iron pipe (DIP) is an outgrowth of the cast-iron pipe industry. Improvements in the metallurgy of cast iron in the 1940s increased the strength of cast-iron pipe and added ductility, an ability to slightly deform without cracking. This was a major advantage and ductile iron pipe quickly became the standard pipe material for high-pressure service for various uses (water, gas, etc.).

**Concrete pipe**

Two types of concrete pipe commonly used today are prestressed concrete cylinder pipe (PCCP) and reinforced concrete pipe (RCP). PCCP is used for force mains, while RCP is used primarily for gravity lines. PCCP may be of either embedded cylinder (EC) or lined-cylinder construction (LC).

The construction process for both the LC and EC begins by casting a concrete core in a steel cylinder. This single process produces the LC pipe. Once the cylinder cures, it is wrapped with a prestressed steel wire and coated with a cement slurry and a dense mortar or concrete coating to produce the EC pipe.

The manufacturing process for reinforced concrete cylinder pipe (RCCP) is similar to embedded cylinder. However, a reinforcing cage and the steel cylinder are positioned within a reusable vertical form and the concrete is cast instead of using the prestressed wire. RCCP can be cured by using either water or steam.

**Plastic pipe**

Plastic pipe is made from either thermoplastic or thermoset plastics. Characteristics and construction vary, but new materials offer high strength and good rigidity. Fluorocarbon plastics are the most resistant to attack from acids, alkalies and organic compounds, but other plastics also have high chemical resistance. Plastic pipe design must include stiffness, loading and hydrostatic design stress requirements for pressure piping.

Thermoplastics are plastic materials that change shape when they are heated. Common plastics used in pipe manufacturing include polyvinyl chloride (PVC), polyethylene (PE or HDPE for High-Density PE), acrylonitrile-butadiene-styrene (ABS) and polybutylene (PB). HDPE is commonly used with pipe bursting.

PVC is strong, lightweight and somewhat flexible. PVC pipe is the most widely used plastic pipe material. Other plastic pipes or composites with plastics and other materials may be more rigid. Thermoset plastics are rigid after they have been manufactured and are not able to be reformed. Thermoset plastic pipes are composed of epoxy, polyester and phenolic resins and are usually reinforced with fiberglass. Resins may contain fillers to extend the resin and to provide specific characteristics to the final material. The glass fibers may be wound around the pipes spirally, in woven configurations or they may be incorporated into the resin material as short strands. The pipes may be centrifugally cast. Stiffness may also be added in construction as external ribs or windings. Reinforced plastic mortar (RPM) and reinforced thermosetting resin (RTR) (or fiberglass reinforced plastic pipe (FRP) are the two basic classes of these pipes. Another name is fiberglass reinforced polymer mortar (FRPM). Thermoset pipes are often manufactured according to the specific buyer requirements and may include liners of different composition for specific chemical uses. For plastic pipes, resins composed of polymerized molecules are mixed with lubricants, stabilizers, fillers and pigments to produce mixtures with different characteristics. Plastic pipes are generally produced by extrusion.

Plastic pipe may be used for sliplining or for rehabilitating existing pipes by inserting or pulling them through a smaller diameter pipe. HDPE pipes may also be used for bursting and upgrading. The smaller diameter pipe may be anchored into place with mortar or grout.

**Vitrified clay pipe**

Vitrified clay pipes are composed of crushed and blended clay that are formed into pipes, then dried and fired in a succession of temperatures. The final firing gives the pipes a glassy finish. Vitrified clay pipes have been used for hundreds of years and are strong, resistant to chemical corrosion, internal abrasion and external chemical attack. They are also heat resistant. These pipes have an increased risk of failure when mortar is used in joints because mortar is more susceptible to chemical attack than the clay. Other types of joints are more chemically stable. It has been shown that the thermal expansion of vitrified clay pipes is less than many other types.

**Applicability**

The applicability of different pipe materials varies with each site and the system requirements. The pipe material must be compatible with the soil and groundwater chemistry. The pipe material also must be compatible with the soil structure and topography of the site, which affects the pipe location and depth, the supports necessary for the pipe fill material and the required strength of the pipe material. The following list shows background information to be used in determining what type of pipe best fits a particular situation:

- Maximum pressure conditions (force mains)
- Overburden, dynamic and static loading
- Lengths of pipe available
- Soil conditions, soil chemistry, water table, stability
- Joining materials required
- Installation equipment required
- Chemical and physical properties of the wastewater
- Joint tightness/thrust control
- Size range requirements
- Field and shop fabrication considerations
- Compatibility with existing systems
- Manholes, pits, sumps and other required structures to be included
- Valves (number, size and cost)
- Corrosion/cathodic protection requirements
- Maintenance requirements.

**Advantages and Disadvantages**

The advantages and disadvantages for specific pipe materials are listed in Table 1. The primary advantages and disadvantages to consider for pipes used in sewer applications include those that are related to construction requirements, pressure requirements (force mains), depth of cover and cost.

**Table 1 - Advantages and Disadvantages of different material**

| *Advantages* | *Disadvantages* |
|---|---|
| **Ductile Iron** | |
| Good corrosion resistance | Heavy |
| High strength | |
| **Concrete** | |
| Good corrosion resistance | Requires careful installation |
| Widespread availability | Heavy |
| High strength | Not $H_2S$ resistant |
| Good load support capacity | |
| **Vitrified Clay** | |
| Resistant to acids and most chemicals | Joints susceptible to chemical attack |
| Strong | Brittle , may crack, careful installations |
| | Short joins and many joints make it prone to infiltration |
| **Thermoplastics (PVC, PE, HDPE, ABS)** | |
| Very lightweight | Susceptible to chemical attack, particularly by solvents |
| Easy to install | Strength affected by sunlight unless UV-protected |
| Economical | Requires special bedding |
| Good corrosion resistance | |
| Smooth surface reduces friction losses | |
| Long pipe sections reduce infiltration potential | |
| Flexible | |
| **Thermosets(FRP)**<br>Corrosion resistant | High installation cost |
| High strength | High material cost |
| Lightweight | Brittle (may crack); requires careful installation |

**Design criteria**

Design requirements may vary greatly. Pipe design is approached differently for both materials and construction methods. The mechanics of the soil that will surround the pipes is a fundamental design aspect for the support characteristics, especially for flexible pipes. The soil type, density and moisture content are important characteristics.

**Bedding**

1. Sewer pipe bedding is the material upon which the pipe is laid and serves as its foundation.
2. Initial backfill is the material surrounding the pipe.
3. Classes of Bedding (LF = Load Factor, Bedding factor from pipe supplier)
    a. 1. Class A1 = LF = 2.2 = Native backfill lightly hand-tamped full cover to crown of pipe with min 100 mm under pipe.
       2. Class A1 = LF = 2.8 = 67 crushed stone full pipe cover with 100 mm min. under pipe.
       3. Class A1 = LF = 3.4 = Reinforced concrete.
    b. 1. Class B = LF = 1.9 = Native soil hand-tamped or granular material to cover half the pipe with min 100 mm under the pipe with hand-placed backfill above.
    c. 1. Class C = LF = 1.5 = shaped trench bottom with full pipe coverage with hand-placed backfill.
       2. Class C = LF = 1.5= Min 100 mm native soil or granular bedding with shaped bottom, full pipe coverage with hand-placed back fill.
    d. 1. Class D = LF = 1.1 = flat or unshaped trench bottom with full pipe coverage with hand-placed backfill.
4. Granular bedding material (Class B&C) may be used to facilitate a true grade on an imperfect or undercut trench bottom. Can also be used to arrange material to accommodate the pipe bells
    a. Granular material is crushed rock aggregate with 1/4-3/4-inch particle size
    b. Advantages
        1. Most commonly used for Class B and C bedding applications
        2. Fairly high BF 1.5-1.9
        3. Moderately priced
        4. Easy to work with
        5. It is superior to sand or pea gravel due to water infiltration/washout.
5. Native soils
    a. Use in place of granular material because it is more available.
    b. Low bedding factor of 1.1 must have undisturbed trench bottom.
    c. Use high-strength pipe.

**Pipe laying**

1. Follow manufacturer's instructions.
2. Use care when unloading at the site to protect the bell and spigot.
3. Use proper-sized lifting equipment.
4. For small diameter pipe <10 inches, it may be hand-laid on the bedding and connected.
5. Larger pipe >10 inches should be supported in place so it can be connected while supported. It may be necessary to use the weight of the pipe to obtain the proper grade.

**Joining of pipe**

1. Most pipes in sanitary WW use a bell on one end and a spigot on the other and a resilient-type gasket to make the joining of the bell and spigot watertight. Most resilient gaskets are the "O" ring type sealed in a groove on the spigot or a mating of rings precast in the bell and on the spigot.
2. Steps to join bell and spigot
    a. Clean bell and spigot.
    b. Lube gasket and place in position.
    c. Guide spigot end of pipe into bell.
    d. Push or pull pipe into place.
    e. Inspect joint and seating of gasket.
    f. Check alignment and grade.

**Costs**

Costs for piping comparisons should include both the costs of the materials as well as the construction costs. The pipe cost is usually given in dollars per unit length, traditionally in $/linear foot, plus the cost of the fittings, connections and joints.

Construction costs will depend on the type of digging necessary, special field equipment requirements and an allowance for in-field adjustments to the system. Access to pipe systems will also be a relevant cost factor, since manhole spacing is dependant on pipe size.

Sanitary sewer construction costs depend on several variables, including:

- depth,
- type of soil,
- presence of rock,
- type of bedding material,
- location (rural vs. urban areas),
- clearing costs, and
- other factors.

Typical pipe materials for small-diameter sanitary sewers (8" through 24" diameter) include:

- PVC,
- vitrified clay, and
- ductile iron.

Typical average costs for sanitary sewers (excluding service connections and manholes) are provided in Table 2. The cost per linear foot in the table is based on an average trench depth of eight feet and excludes service connections and manholes.

The following are **not** included in the cost per linear foot:

- asphalt and gravel driveway repair,
- open cut of roads,
- boring and jacking,

- concrete encasement of pipe at stream crossings or other locations,
- erosion control and
- relocation of other utilities.

Soil material is assumed to be silt, clay or other soil mixtures with no requirement for shoring, rock removal or dewatering.

**Table 2 - Average cost/linear foot by pipe diameter**
(Dollars based on 2009 data)

| Pipe materials | 2” | 4” | 6” | 8” | 12” | 15” | 18” | 24” |
|---|---|---|---|---|---|---|---|---|
| Vitrified Clay | | | $33 | $40 | $50 | $67 | $87 | $146 |
| Ductile Iron | | | | $50 | $67 | NA | $100 | $146 |
| Reinforced concrete | | | | | $15 | $23 | $30 | $40 |
| PVC | $20 | $25 | $31 | $33 | $40 | $50 | $67 | $100 |
| PE | | $9 | $16 | $19 | | | | |
| Fiberglass-reinforced | $28 | $40 | $53 | $80 | | | | |
| ABS | $14 | | | | | | | |

## GRAVITY SYSTEMS

Sewers are hydraulic conveyance structures that carry wastewater to a treatment plant or other authorized point of discharge. A typical method of conveyance used in sewer systems is to transport wastewater by gravity along a downward-sloping pipe gradient.

These sewers, known as conventional gravity sewers, are designed so that the slope and size of the pipe is adequate to maintain flow towards the discharge point without surcharging manholes or pressurizing the pipe. Sewers are commonly referred to according to the type of wastewater that each transports. For example, storm sewers carry stormwater, and industrial sewers carry industrial wastes. Sanitary sewers carry both domestic sewage and industrial wastes.

Another type of sewer, known as a combined sewer, is prevalent in older communities, but such systems are no longer constructed. Combined sewers carry domestic sewage, industrial waste and stormwater.

Conventional gravity sewers are typically used in urban areas with consistently sloping ground because excessively hilly or flat areas result in deep excavations and drive up construction costs. Conventional gravity sewers remain the most common technology used to collect and transport domestic wastewater.

**Types of sewers**

BUILDING SEWERS are what connect a building's internal wastewater collection system to the municipal sewer system. They can connect to a lateral, main or trunk sewer line.

LATERAL and BRANCH SEWERS are the upper ends of the municipal sewer system. Laterals dead-end at their upstream end with branch sewers collecting the wastewater from several lateral sewer lines.

MAIN SEWERS are collectors for numerous lateral and branch sewers from an area of several hundred acres or a specific neighborhood or housing development. They convey the wastewater to larger trunk sewer lines, to lift stations or to a neighborhood package wastewater treatment plant.

TRUNK SEWERS serve as the main arteries of the wastewater collection system. They collect and convey the wastewater from numerous main sewer lines either to a wastewater treatment plant or to a interceptor sewer.

INTERCEPTOR SEWERS receive the wastewater numerous from trunk sewers and convey it to a wastewater treatment plant. These are the largest diameter lines in the sewer system and the furthest downstream in the system.

**Advantages**

Conventional gravity sewer systems have been used for many years and procedures for their design are well-established. When properly designed and constructed, conventional gravity systems perform reliably.

Properly designed and constructed conventional gravity sewers provide the following advantages:

- Can handle grit and solids in sanitary sewage.
- Can maintain a minimum velocity (at design flow), reducing the production of hydrogen sulfide and methane. This in turn reduces odors, blockages, pipe corrosion and the potential for explosion (Qasim 1994).

**Disadvantages**

- The slope requirements to maintain gravity flow can require deep excavations in hilly or flat terrain, driving up construction costs.
- Sewage pumping or lift stations may be necessary as a result of the slope requirements for conventional gravity sewers, which result in a system terminus (i.e., low spot) at the tail of the sewer, where sewage collects and must be pumped or lifted to a collection system. Pumping and lift stations substantially increase the cost of the collection system.
- Manholes associated with conventional gravity sewers are a source of inflow and infiltration, increasing the volume of wastewater to be carried, as well as the size of pipes and lift/pumping stations, and, ultimately, increasing costs.

**Design criteria**

The design of conventional gravity sewers is based on the following design criteria:

- long-term serviceability,
- design flow (average and peak),
- minimum pipe diameter,
- velocity,
- slope,
- depth of bury and loads on buried conduits,
- appurtenances and
- site conditions.

**Long-term serviceability**

The design of long-lived sewer infrastructure should consider serviceability factors, such as ease of installation, design period, useful life of the conduit, resistance to infiltration and corrosion and maintenance requirements. The design period should be based on the ultimate tributary population and usually ranges from 25 to 50 years (Qasim, 1994).

**Design flow**

Sanitary sewers are designed to carry peak residential, commercial, institutional and industrial flows, as well as infiltration and inflow. Gravity sewers are designed to flow full at the design peak flow. Design flows are based on various types of developments. Table 1 provides a list of design flow for various development types.

**Table 1 - Average design flows for development types**

| Type of development | Design flow/GPD |
|---|---|
| **Residential** | |
| general | 100 / person |
| single family | 370 / residence |
| townhouse unit | 300 / unit |
| apartment unit | 300 / unit |
| **Commercial** | |
| general | 2,000 / acre |
| motel | 130 / unit |
| office | 20 / employee |
| | 0.20/net sq. ft. |
| **Industrial** | |
| general | 10,000 / acre |
| warehouse | 600 / acre |
| school site (general) | 16 / student |

**Minimum pipe size**

A minimum pipe size is dictated in gravity sewer design to reduce the possibility of clogging. The minimum pipe diameter recommended by the Ten State Standards is 200 mm (8 inches). Though the Ten State Standards are adopted by ten specific states

(Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania and Wisconsin) and the Province of Ontario, they often provide the basis for other state standards.

**Velocity**

The velocity of wastewater is an important parameter in a sewer design. A minimum velocity must be maintained to reduce solids deposition in the sewer, and most states specify a minimum velocity that must be maintained under low-flow conditions. The typical design velocity for low-flow conditions is 0.3 m/s (1 foot/second). During peak dry weather conditions, the sewer lines must attain a velocity greater than 0.6 m/s (2 feet/second) to ensure that the lines will be self-cleaning (i.e., they will be flushed out once or twice a day by a higher velocity). Velocities higher than 3.0 m/s (10 feet/second) should be avoided because they may cause erosion and damage to sewers and manholes (Qasim, 1994).

**Slope**

Sewer pipes must be adequately sloped to reduce solids deposition and production of hydrogen sulfide and methane. Table 2 presents a list of minimum slopes for various pipe sizes. If a sewer slope of less than the recommended value must be provided, the responsible review agencies may require depth and velocity computations at minimum, average and peak flow conditions. The size of the pipe may change if the slope of the pipe is increased or decreased to ensure a proper depth below grade. Velocity and flow depth may also be affected if the slope of the pipe changes. This parameter must receive careful consideration when designing a sewer.

**Table 2 - Minimum slopes[1] for various pipe lengths**

| DIAMETER | PIPE | LENGTH |
|---|---|---|
| INCHES | Up to 5 ft | 6 ft or more |
| 8 | 0.47 | 0.42 |
| 10 | 0.34 | 0.31 |
| 12 | 0.26 | 0.24 |
| 14 | 0.23 | 0.22 |
| 24 | 0.08 | 0.088 |
| 30 | 0.07 | 0.07 |

**1=slopes in feet per 100 ft.**

**Depth of bury**

Depth of bury affects many aspects of sewer design. Slope requirements may drive the pipe deep into the ground, increasing the amount of excavation required to install the pipe. Sewer depth averages 1 to 2 m (3 to 6.5 feet) below the ground surface. The proper depth of bury depends on the water table, the lowest point to be served (such as a ground floor or basement), the topography of the ground in the service area and the depth of the frost line below grade.

**Appurtenances**
Appurtenances are devices that facilitate and control the flow of wastewater and allow access for maintenance activities. They include manholes, building connections, junction chambers or boxes and terminal cleanouts, among others. Regulations for using appurtenances in sewer systems are well-documented in municipal design standards and/or public facility manuals.

Manholes for small sewers (610 mm [24 inches] in diameter or less) are typically 1.2 m (4 feet) in diameter. Larger sewers require larger manhole bases, but the 1.2 m (4-foot) barrel may still be used.

Manhole spacing depends on regulations established by the local municipality. Manholes are typically required when there is a change of sewer direction. However, certain minimum standards are typically required to ensure access to the sewer for maintenance. Typical manhole spacing ranges between 90 to 180 m (300 to 600 feet), depending on the size of the sewer and available sewer cleaning equipment. For example, one municipality requires that the maximum manhole spacing be at intervals not to exceed 120 m (400 feet) on all sewers 380 mm (15 inches) or less, and not exceeding 150 m (500 feet) on all sewers larger than 380 mm (15 inches) in diameter.

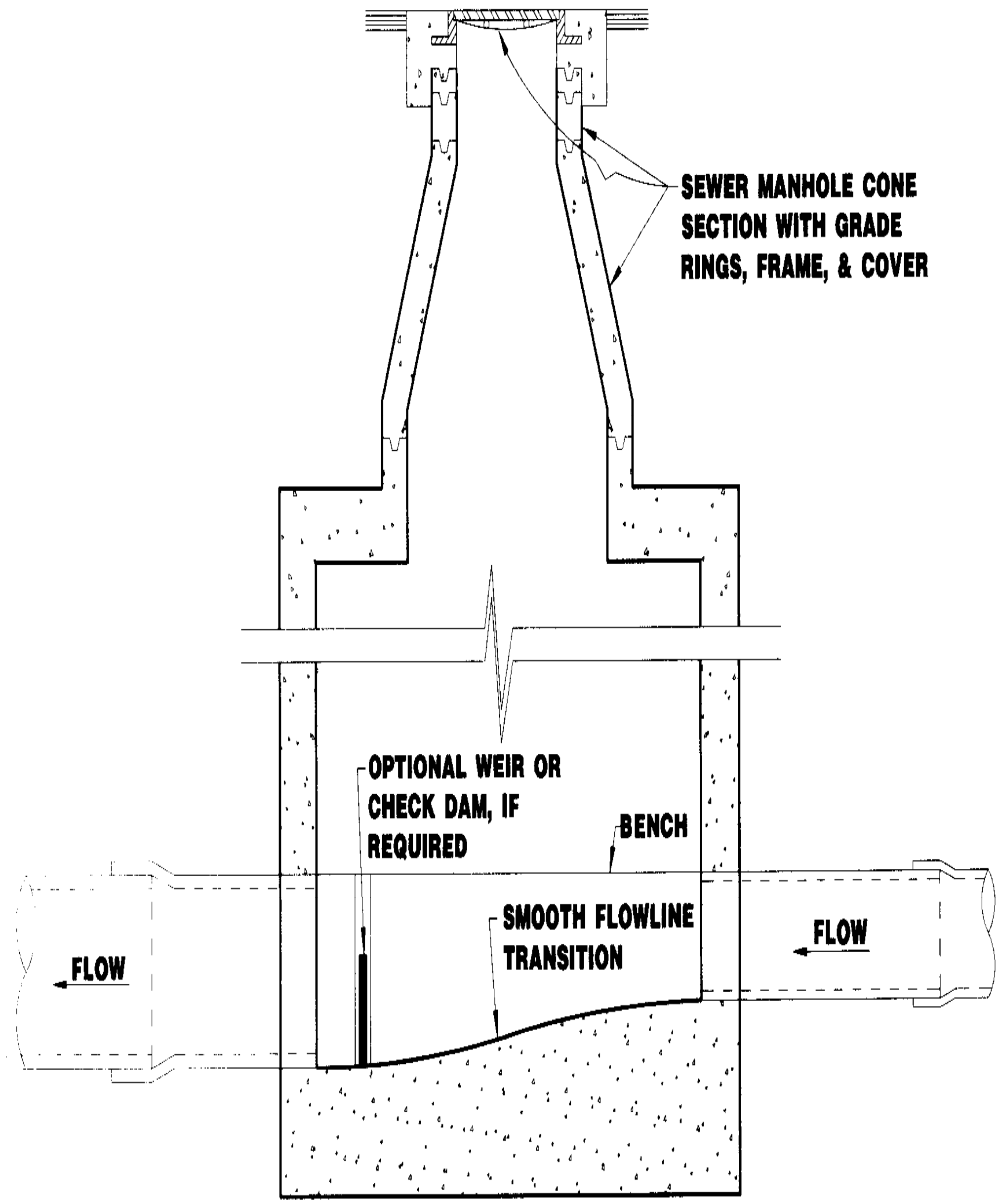
Manholes are installed in the following:
- lateral,
- main,
- trunk, and
- interceptor.

Manholes are used to place persons, equipment and materials in these sewers for inspection, maintenance and solids removal from cleaning operations. Manholes, on straight runs, should be spaced between 300 and 600 ft. Manholes are also placed at changes in:
- slope,
- elevation,
- direction,
- pipe size and
- junctions.

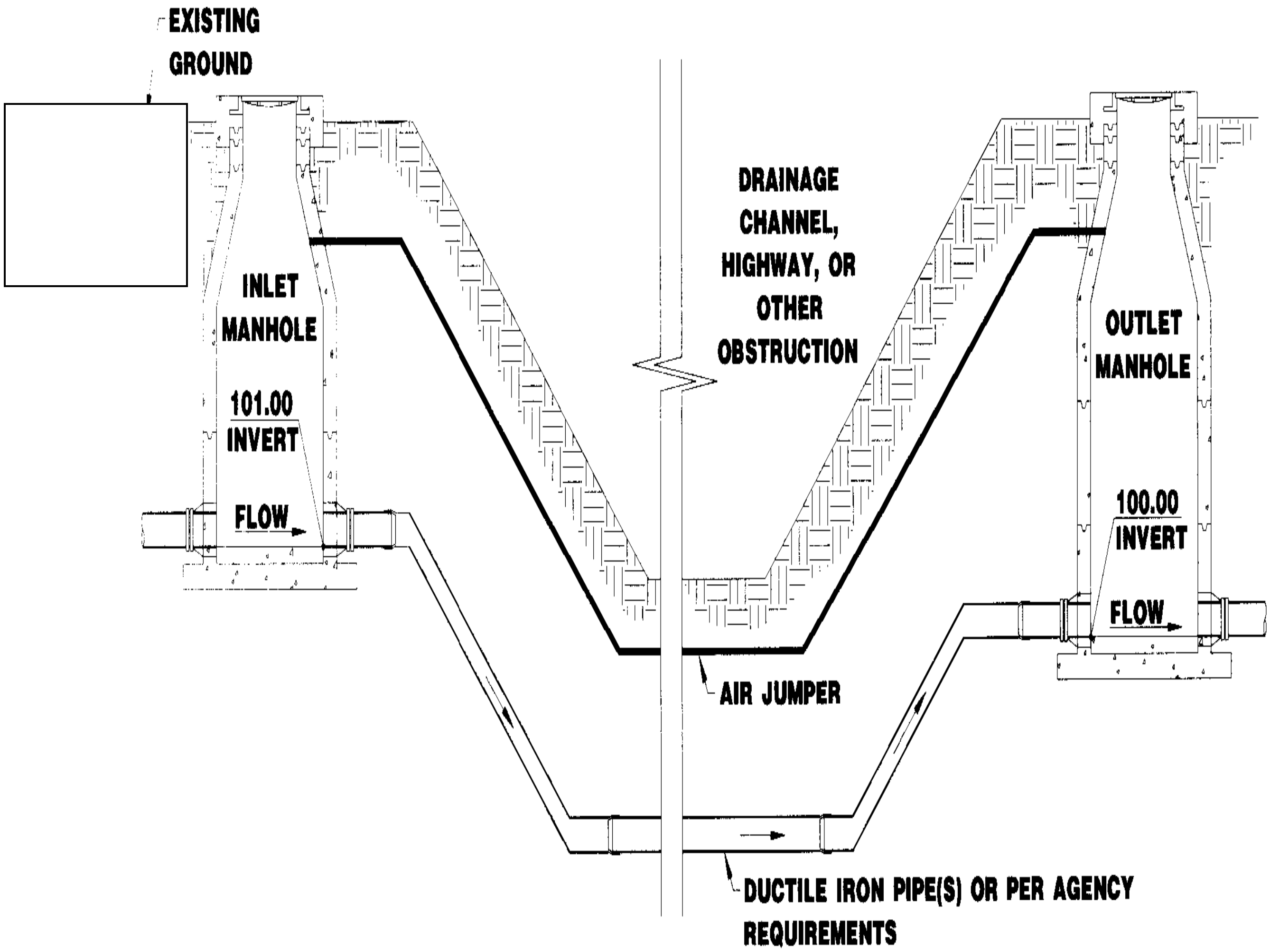
Drop manholes should be used when the difference in elevation between the influent and the effluent of the manhole cannot handle the drop into the barrel without creating excessive turbulence, which reduces the production of $H_2S$.

Back flow preventers are used to stop the accidental backflow or reverse flow of WW into buildings. They are used when the lowest overflow point in the building's plumbing is above the rim elevation line of the manhole in the lateral or street main immediately upstream of the building's sewer connection. There are two types, the mechanical check valves and the atmospheric overflow device with floatable ball seal.

Junction structures are used to join large diameter sewers without a manhole. They usually contain a structure that “breaks” the turbulence, thus reducing the possibility of $H_2S$ production.




Inverted siphons are sewer lines installed lower than the normal gradient to pass under obstructions, such as streams and roadways. Wastewater is “pushed” thru the siphon by the pressure because the upstream sewer, at a junction box, is higher than the downstream sewer. Siphons need more maintenance due to the slowing of flow and solids build up. Air jumpers are used to equalize air pressure on inverted siphons.




*NOTE:* Air jumpers are sometimes constructed as part of an inverted siphon. Since the siphon is completely filled with wastewater, a blockage in the flow of air in the sewer line occurs without an air jumper. This blockage may cause a continuous release of toxic, odorous, and corrosive hydrogen sulfide at the up-stream siphon manhole. Installation of air jumpers prevents this from happening by providing the downstream flow of air that usually occurs above the wastewater in a partially filled sewer line.

**Operation and Maintenance**
Interruptions in sewer service may be avoided by strict enforcement of sewer ordinances and timely maintenance of sewer systems. Regular inspection and maintenance minimize the possibility of damage to private property by sewer stoppages, as well as the legal responsibility of the sewer authority for any damages.

An operation and maintenance program is necessary and should be developed to ensure the most trouble-free operation of a sanitary sewer system. An effective maintenance program includes enforcement of sewer ordinances, timely sewer cleaning and inspection, and preventive maintenance and repairs. Inspection programs often use closed-circuit television (CCTV) cameras and lamping to assess sewer conditions.

Sewer cleaning clears blockages and serves as a preventive maintenance tool. Common sewer cleaning methods include rodding, flushing, jetting and bailing. Education and pollution prevention can enhance operation and maintenance programs by informing the public of proper grease disposal methods.

Effective operation of a conventional gravity sewer begins with proper design and construction. Serious problems may develop without an effective preventative maintenance program. Occasionally, factors beyond the control of the maintenance crew can cause problems. Potential problems include:

- explosions or severe corrosion due to discharge of uncontrolled industrial wastes;
- odors;
- corrosion of sewer lines and manholes due to generation of hydrogen sulfide gas;
- collapse of the sewer due to overburden or corrosion; and
- Poor construction, workmanship or earth shifts may cause pipes to break or joints to open up. Excessive infiltration/exfiltration may occur.
- Protruding taps in the sewers caused by improper workmanship (known as plumber taps or hammer taps). These taps substantially reduce line capacity and contribute to frequent blockages.
- Excessive settling of solids in the manhole and sewer line may lead to obstruction, blockage or generation of undesired gases.
- The diameter of the sewer line may be reduced by accumulation of slime, grease and viscous materials on the pipe walls, leading to blockage of the line.
- Faulty, loose or improperly fitting manhole covers can be a source of noise as well as inflow.
- Ground shifting may cause cracks in manhole walls or pipe joints at the manhole, which become a source of infiltration or exfiltration.
- Debris (i.e., rags, sand, gravel, sticks, etc.) may collect in the manhole and block the lines.
- Tree roots may enter manholes through the cracks, joints or a faulty cover, and cause serious blockages.

**Costs**

The cost of a conventional gravity sewer system varies, based on many factors, including the depth and difficulty of excavation, the cost of labor, availability of pipe, geologic conditions, hydraulic grade line and construction sequencing. As such, it is difficult to quantify the cost per linear foot for a particular sewer pipe size.

**Table 3 - Unit costs for sanitary sewer**

| ITEM | UNIT COST (2009) |
|---|---|
| PVC pipe (not including excavation | |
| 8” diameter | $5.85 |
| 10” diameter | $9.05 |
| 15” diameter | $18.35 |
| Brick Manhole 4 ft ID 4 ft deep | $1,100.00 |
| Concert Cast in place 4 ft X4 ft X 8 in | $1,000.00 |
| Trenching 4 ft wide 6 ft deep | $28.00 per ft |
| Pipe bedding side slope 0, 1-4 ft wide | $5.25 per ft |
| Fill by dozer no compaction | $1.90 cu yd. |
| | |

## PUMPS and MOTORS

1. Categories of pumps:

   A. They may be classified by the character of the material handled – raw wastewater, grit, effluent, activated sludge, raw sludge or digested sludge.

   B. They may be classified by pumping conditions – high lift, low lift, recirculation or high capacity.

   C. They may be classified by the principle of operation – centrifugal, propeller, reciprocating, incline screw, progressive cavity or pneumatic ejector.

2. Centrifugal pumps: These pumps have an impeller (paddle-wheel type piece) rotating in a casing. The impeller is supported on a shaft, which is then supported by bearings. Liquid enters the casing through the eye (at the center) of the impeller. It is then picked up by the curved impeller vanes and by the rotation of the impeller and is thrown out by the centrifugal force into the discharge. Impellers usually have large openings at their center to prevent clogging. A screen should be used at the intake end of the suction piping to prevent clogging. Impellers may be in closed casings or they may be open if the pump is submersible and being used to pump wastewater from lift station wet wells. The motor or drive mechanism can be connected directly to the shaft or connected by a coupling flange depending upon the application.

A. <u>Shaft sleeves</u> are used to cover the shaft that supports the impeller to protect the shaft from the corrosive and abrasive effects of the liquid going through the pump. The sleeves are mounted to the shaft on ball or roller bearings.

B. <u>Wearing rings</u> are used to plug the space between the impeller and the casing to prevent internal liquid leakage. These rings are either attached to the casing, the impeller or both. Wearing rings should be inspected regularly and replaced when serious wear or leakage is observed. Since water is the lubricant between the rings and the impeller, a pump should never be allowed to run dry.

C. <u>Stuffing boxes</u> are used to prevent air from being sucked into the pump. Air affects the efficiency of the pump and could cause it to lose prime. It consists of a casing containing rings of packing and a gland or membrane at the outside end. Water is used in the stuffing box to block out the intake of air and to lubricate the packing. The water is brought into a seal cage in the center of the stuffing box under pressure by connector piping to a point near the impeller rim *provided it is clean liquid.* If the liquid being pumped contains grit or other solids, it may be necessary to use potable water to provide the seal. To prevent the possibility of a cross-connection, the connection with the potable water supply must include either an <u>air gap separation</u> or an <u>approved backflow preventer.</u> The end gland or membrane is used to control liquid flow from the stuffing box. The gland should be tightened just enough such that a thin stream of water flows from the stuffing box. <u>Excessive leakage</u> is indicative of the need to replace the packing.

D. <u>Lantern rings</u> provide the water seal connection between the water supply line and the stuffing box. When packing is being replaced, the lantern ring should be completely filled with grease (if grease seals are used) before all the rings of packing are in place.

E. The <u>efficiency</u> of centrifugal non-clog pumps starts at zero at shut-off and increases rapidly until a peak is reached at approximately the mid-point of the overall capacity range of the pump. Therefore, for peak efficiency, best mechanical performance and quietest operation; a pump should be selected so that the range of operation will be at the mid-point of the total pump curve. They should be operated near their rated heads (pressure). Otherwise, the pump is apt to operate under unsatisfactory and unstable conditions, which reduce the efficiency and operating life of the unit.

3. Propeller pumps: Two basic types.

A. Axial-flow pumps have flow parallel to the axis of the impeller.

B. Mixed-flow pumps have flow that is both axial and radial (perpendicular to the shaft) to the impeller.

4. Reciprocating or piston pumps: Pumps used to move sludge by a piston that moves back and forth. Reciprocating pumps should <u>never</u> be allowed to pump against a closed discharge valve due to a build up of pressure that could damage the pump and/or the piping.

5. Incline screw pumps: An auger-type pump housed in a trough that is on an incline. The auger is supported by bearings on both ends. The screw or auger operates at a constant speed moving the wastewater up the trough to a point of discharge. These are commonly used on influent and effluent waste streams where low-lift, high-capacity, non-clog pumping is required. They may range in size from 12 to 144 inches in diameter, with rated capacities from 100 to 70,000 gpm. They are primarily suited for lifts up to 25 feet, but are available for higher lifts.

6. Progressive cavity pumps: These are similar to incline screw pumps, except that the screw-shaped rotor is enclosed in a housing (stator). The spacing between the rotor and the inside casing walls form a series of cavities. As the rotor turns, the threads make contact with the walls and move the water along in auger fashion. The size of the cavities along the rotor determines the capacity of the pump. These pumps are recommended for liquids containing higher concentrations of solids. Like reciprocating pumps, they should never be operated dry, nor against a closed discharge valve.

7. Pneumatic ejectors (Air Lift): An air lift ejector consists of a receiving container, inlet and outlet check valve, air supply and liquid level detector. When the wastewater reaches a preset level, air is forced into the container, ejecting the wastewater. Following the discharge cycle, the air supply is cut off and wastewater flows through the inlet into the receiver. With flow ranges from 30 to 150 gpm, they are mostly used for pumping raw wastewater. These pumps are capable of passing solids up to the size of the inlet and discharge valves since there is nothing on the inside of the ejector-receiver to restrict the flow. They are, however, a high-maintenance problem. If a stick or other object gets stuck in either check valve, the ejector will not operate.

8. Maintenance of pump motors:

   A. Check the condition of the motor for dirt, dust, moisture, air circulation obstructions, and excessive leakage of grease from the bearings.

   B. Observe any unusual conditions, including noise, excessive heat, vibration, intermittent to continuous sparking of brushes or sluggish operation. A <u>stethoscope</u> is sometimes used to check for bearing whines, gratings or uneven noises.

   C. Keep close watch on the amperage being pulled by the motors. A sudden increase could be indicative of a pumping restriction, while a sudden decrease may be the result of a drop in pumping head caused by a break in the discharge line.

D. For motors wound for 3-phase current, periodically check to ensure equal distribution across all three phases. If one phase cuts out while in operation, the motor may overheat and become damaged unless it is stopped by a thermal control device.

9. Pump Operating Problems and Causes of Failure or Reduced Operating Efficiency:

A. Causes for pump not starting:

(1.) Blown fuses or circuit breakers due to: (a) Rating of fuses or circuit breakers not correct, (b) Switch (breaker) contacts corroded or shorted, (c) Terminal connections loose or broken somewhere in the circuit, (d) Automatic control mechanism not functioning properly, (e) Motor shorted or burned out, (f) Wiring hookup or service not correct, (g) Switches not set for operation, (h) Contacts of the control relays dirty and arcing, (i) Fuses or thermal units too warm, (j) Wiring short-circuited, (k) Shaft binding or sticking due to rubbing impeller, tight packing glands or clogging of pump; or

(2.) Loose connection, fuse or thermal unit.

B. Causes for reduced pump discharge rates:

(1) Pump not primed, (2) Mixture of air in the wastewater, (3) Speed of motor too low, (4) Improper wiring, (5) Defective motor, (6) Discharge head too high, (7) Suction lift higher than anticipated, (8) Impeller clogged, (9) Discharge line clogged, (10) Pump rotating in wrong direction, (11) Air leaks in suction line or packing box, (12) Inlet to suction too high, permitting air to enter, (13) Valves partially or entirely closed, (14) Check valves stuck or clogged, (15) Incorrect impeller adjustment, (16) Impeller damaged or worn, (17) Packing worn or defective, (18) Impeller turning on shaft because of broken key, (19) Flexible coupling broken, (20) Loss of suction during pumping, which may be caused by leaky suction line, ineffective water or grease seal, (21) Belts slipping, or (22) Worn wearing ring.

C. Causes for high power requirements:

(1) Speed of rotation too high, (2) Operating heads lower than rating for which pump was designed, resulting in excess pumping rates, (3) Check valves open, draining long force-main back into wet-wall, (4) Specific gravity or viscosity of liquid pumped too high, (5) Clogged pump, (6) Sheaves on belt drive misaligned or maladjusted, (7) Pump shaft bent, (8) Rotating elements binding, (9) Packing too tight, (10) Wearing rings worn or binding, or (11) Impeller rubbing.

D. Causes for noisy pump operation:

(1) Pump not completely primed, (2) Inlet clogged, (3) Inlet not submerged, (4) Pump not lubricated properly, (5) Worn impellers, (6) Strain on pumps caused by unsupported piping fastened to the pump, (7) Foundation insecure, (8) Mechanical defects in pump, (9) Misalignment of motor and pump where connected by flexible shaft, or (10) Rags or sticks bound (wrapped) around impeller.

## LIFT STATIONS

### Description

Wastewater lift stations are facilities designed to move wastewater from lower to higher elevation through pipes. Key elements of lift stations include a wastewater receiving well (wet-well), often equipped with a screen or grinding to remove coarse materials; pumps and piping with associated valves; motors; a power supply system; an equipment control and alarm system and an odor control system and ventilation system.

Lift station equipment and systems are often installed in an enclosed structure. They can be constructed on-site (custom-designed) or prefabricated. Lift station capacities range from 76 liters per minute (20 gallons per minute) to more than 378,500 liters per minute (100,000 gallons per minute). Prefabricated lift stations generally have capacities of up to 38,000 liters per minute (10,000 gallons per minute).

Centrifugal pumps are commonly used in lift stations. A trapped air column, or bubbler system, that senses pressure and level is commonly used for pump station control. Other control alternatives include electrodes placed at cut-off levels, floats, mechanical clutches and floating mercury switches. A more sophisticated control operation involves the use of variable speed drives.

Lift stations are typically provided with equipment for easy pump removal. Floor access hatches or openings above the pump room and an overhead monorail beam, bridge crane, or portable hoist are commonly used.

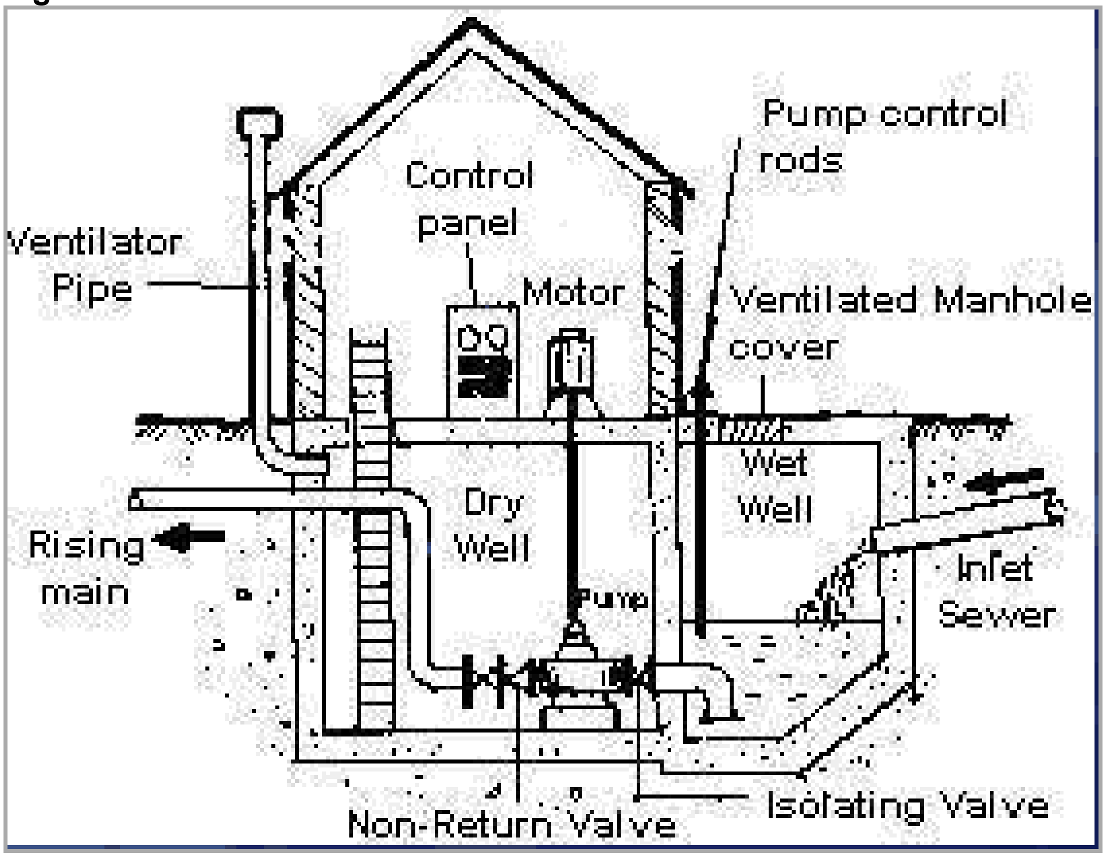
The two most common types of lift stations are the dry-pit or dry-well and submersible lift stations. In dry-well lift stations, pumps and valves are housed in a pump room (dry pit or dry well), that is easily accessible. The wet well is a separate chamber attached or located adjacent to the dry-well (pump room) structure. **Figures 1 and 2** illustrate the two types of pumps.

Submersible lift stations do not have a separate pump room; the lift station header piping, associated valves, and flow meters are located in a separate dry vault at grade for easy access. Submersible lift stations include sealed pumps that operate submerged in the wet well. These are removed to the surface periodically and reinstalled using guide rails and a hoist.

A key advantage of dry-well lift stations is that they allow easy access for routine visual inspection and maintenance. In general, they are easier to repair than submersible pumps. An advantage of submersible lift stations is that they typically cost less than dry-well stations and operate without frequent pump maintenance. Submersible lift stations do not usually include large aboveground structures and tend to blend in with their surrounding environment in residential areas. They require less space and are easier and less expensive to construct. Prefabricated pump stations are available in various forms and can be either dry-well or submersible. Prefabricated pump stations are typically used for smaller flows because they are more compact and generally lower in cost than custom-designed pump stations. Prefabricated drywell pump stations usually include steel or a plastic shell that is designed to house one to three vertical shaft flooded suction pumps. Pumps, valves and other equipment are installed at the factory prior to shipment.

Circular station shells are more common and larger pump stations can have an oval shape. Pump station shells are typically bolted to cast-in-place concrete base slabs at the job site. In wet-well configurations, the wet well usually is constructed of precast concrete. Prefabricated submersible stations are typically constructed of precast concrete or steel and can accommodate one or two submersible pumps. For precast concrete stations, the pump manufacturer may provide a complete package of equipment, including submersible pumps, discharge elbows, check valves, access hatches and level controls. For steel stations, the equipment is typically prepackaged at the factory. Fiberglass tanks are typically used for smaller pump stations.

**Figure 1**

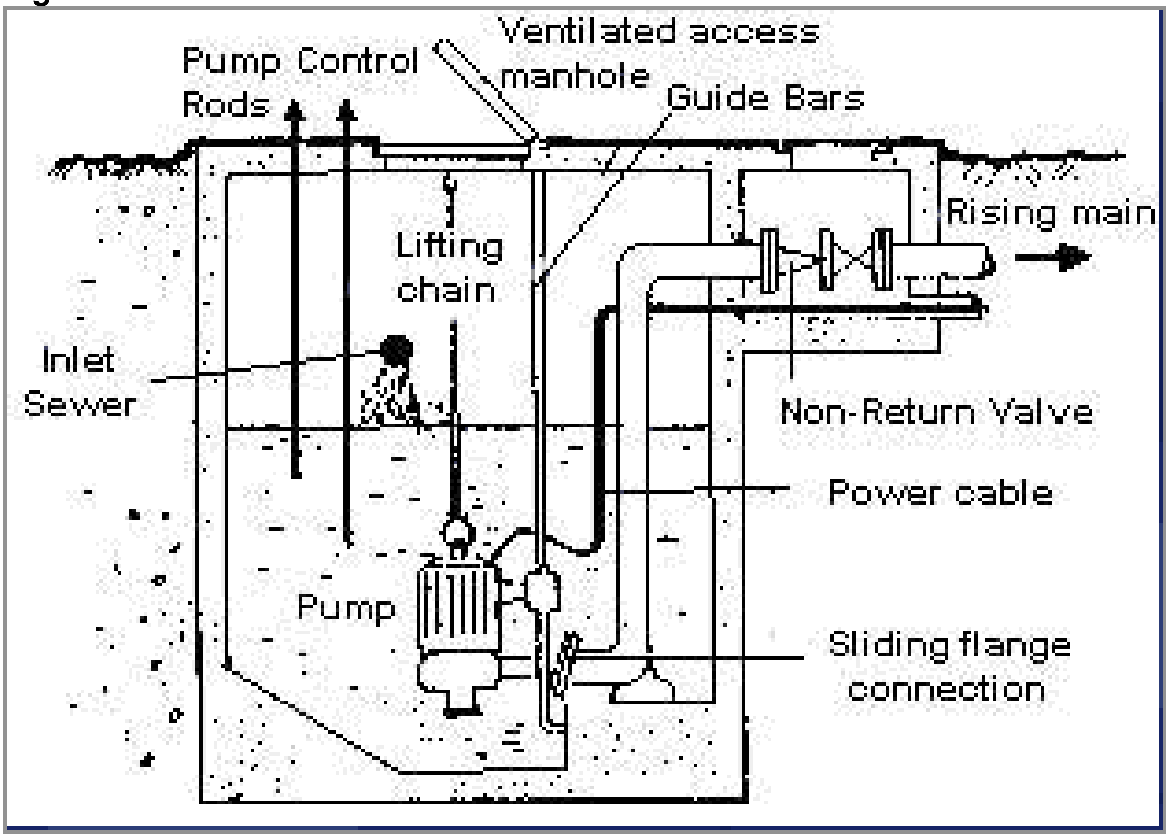



**Applicability**
Lift stations are used to move wastewater from lower to higher elevation, particularly where the elevation of the source is not sufficient for gravity flow and/or when the use of gravity conveyance will result in excessive excavation depths and high sewer construction costs.

**Current status**
Lift stations are widely used in wastewater conveyance systems. Dry-well lift stations have been used in the industry for many years. However, the current industry-wide trend is to replace drywell lift stations of small and medium size (typically less than 24,000 liters per minute or 6,350 gallons per minute) with submersible lift stations mainly because of lower costs, a smaller footprint and simplified operation and maintenance.

Variable speed pumping is often used to optimize pump performance and minimize power use. Several types of variable-speed pumping equipment are available, including variable voltage and frequency drives, eddy current couplings and mechanical variable-speed drives. Variable-speed pumping can reduce the size and cost of the wetwell and allows the pumps to operate at maximum efficiency under a variety of flow conditions. Because variable-speed pumping allows lift station discharge to match inflow, only nominal wet-well storage volume is required and the well water level is maintained at a near constant elevation.

**Figure 2**




Variable-speed pumping may allow a given flow range to be achieved with fewer pumps than a constant-speed alternative. Variable-speed stations also minimize the number of pump starts and stops, reducing mechanical wear. Although there is significant energy-saving potential for stations with large friction losses, it may not justify the additional capital costs unless the cost of power is relatively high. Variable speed equipment also requires more room within the lift station and may produce more noise and heat than constant speed pumps.

Lift stations are complex facilities with many auxiliary systems. Therefore, they are less reliable than gravity wastewater conveyance. However, lift station reliability can be significantly improved by providing standby equipment (pumps and controls) and emergency power supply systems. In addition, lift station reliability is improved by using non-clog pumps suitable for the particular wastewater quality and by applying emergency alarm and automatic control systems.

Modern pump stations are equipped with automatic controls for pump starting and operational sequencing. The pump stations typically have standby pumps to increase reliability and provide adequate capacity for unusually high flows. In unattended pumping stations, automatic controllers are frequently used to allow switchover to standby units when a pump fails. Flow recording equipment is often installed to record instantaneous pumping rates and the total flow pumped.

The useful life of pump station equipment is typically limited to 20 to 30 years, with good maintenance. Pump station structures typically have a useful life of 50 years. The useful life of pump station equipment and structures can be prolonged by using corrosion-resistant materials and protective coatings.

**Advantages**
Lift stations are used to reduce the capital cost of sewer system construction. When gravity sewers are installed in trenches deeper than three meters (10 feet), the cost of sewer line installation increases significantly because of the more complex and costly excavation equipment and trench-shoring techniques required. The size of the gravity sewer lines is dependent on the minimum pipe slope and flow. Pumping wastewater can convey the same flow using smaller pipeline size at shallower depth, and thereby, reducing pipeline costs.

**Disadvantages**
Compared to sewer lines where gravity drives wastewater flow, lift stations require a source of electric power. If the power supply is interrupted, flow conveyance is discontinued and can result in flooding upstream of the lift station, It can also interrupt the normal operation of the downstream wastewater conveyance and treatment facilities. This limitation is typically addressed by providing an emergency power supply.

Key disadvantages of lift stations include the high cost to construct and maintain and the potential for odors and noise. Lift stations also require a significant amount of power, are sometimes expensive to upgrade and may create public concerns and negative public reaction. The low cost of gravity wastewater conveyance and the higher costs of building, operating and maintaining lift stations means that wastewater pumping should be avoided, if possible and technically feasible.

Wastewater pumping can be eliminated or reduced by selecting alternative sewer routes or extending a gravity sewer using direction drilling or other state-of-the-art deep excavation methods. If such alternatives are viable, a cost benefit analysis can determine if a lift station is the most viable choice.

**Reliability**
Pump stations are complex facilities that contain a significant number of equipment and auxiliary systems. Therefore, they are less reliable than gravity wastewater conveyance, but the pump station reliability can be significantly improved.

A way to improve the situation is by providing standby equipment (pumps and controls) and emergency power supply systems. In addition, pump station reliability is improved by using screens to remove debris, by using non-clog pumps suitable for the particular wastewater quality and by applying emergency alarm and automatic control systems.

In an emergency (pump malfunction, power failure, etc.) a portion of the wastewater conveyed to the pump station may overflow to nearby surface waters causing potential health risk. Emergency sewer overflows are mitigated by installation of highly reliable equipment, providing redundant control systems and installing facilities for overflow storage and/or treatment prior to discharge to surface waters.

Potential odor problems are mitigated by installation of various odor control systems, including reduction of odor release by adding chemicals upstream of the pump station and odorous gases evacuation and treatment at the pump.

**Design criteria**
Cost-effective lift stations are designed to:

- Match pump capacity, type and configuration with wastewater quantity and quality;
- Provide reliable and uninterruptible operation;
- Allow for easy operation and maintenance of the installed equipment;
- Accommodate future capacity expansion;
- Avoid septic conditions and excessive release of odors in the collection system and at the lift station;
- Minimize environmental and landscape impacts on the surrounding residential and commercial developments and
- Avoid flooding of the lift station and the surrounding areas.

**Wet-well**
Wet-well design depends on the type of lift station configuration (submersible or dry well) and the type of pump controls (constant or variable speed). Wet wells are typically designed large enough to prevent rapid pump cycling, but small enough to prevent a long detention time and associated odor release.

Wet-well maximum detention time in constant speed pumps is typically 20 to 30 minutes. Use of variable frequency drives for pump speed control allows wet-well detention time reduction to 5 to 15 minutes. The minimum recommended wet-well bottom slope is to 2:1 to allow self-cleaning and a minimum deposit of debris.

Effective volume of the wet well may include sewer pipelines, especially when variable speed drives are used. Wet wells should always hold some level of sewage to minimize odor release. Bar screens or grinders are often installed in or upstream of the wet-well to minimize pump clogging problems.

**Wastewater pumps**
The number of wastewater pumps and associated capacity should be selected to provide head capacity characteristics that correspond as nearly as possible to wastewater quantity fluctuations. This can be accomplished by preparing pump/pipeline system head-capacity curves showing all conditions of head (elevation of a free surface of water) and capacity under which the pumps will be required to operate.

The number of pumps to be installed in a lift station depends on the station capacity, the range of flow and the regulations. In small stations with maximum inflows of less than 2,640 liters per minute (700 gallons per minute), two pumps are customarily installed, with each unit able to meet the maximum influent rate. For larger lift stations, the size and number of pumps should be selected so that the range of influent flow rates can be met without starting and stopping pumps too frequently and without excessive wet-well storage. Depending on the system, the pumps are designed to run at a reduced rate.

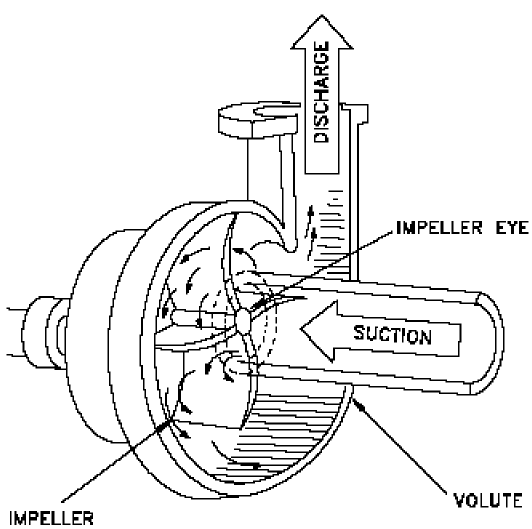
The pumps may also alternate to equalize wear and tear. Additional pumps may provide intermediate capacities better matched to typical daily flows. An alternative option is to provide flow flexibility with variable speed pumps.

For pump stations with high head losses, the single pump flow approach is usually the most suitable. Parallel pumping is not as effective for such stations because two pumps operating together yield only slightly higher flows than one pump. If the peak flow is to be achieved with multiple pumps in parallel, the lift station must be equipped with at least three pumps: two duty pumps that together provide peak flow and one standby pump for emergency backup.

Parallel peak pumping is typically used in large lift stations with relatively flat system head curves. Such curves allow multiple pumps to deliver substantially more flow than a single pump. The use of multiple pumps in parallel provides more flexibility.

Several types of centrifugal pumps are used in wastewater lift stations. In the straight-flow centrifugal pumps, wastewater does not change direction as it passes through the pumps and into the discharge pipe. These pumps are well suited for low-flow/high-head conditions. In angle-flow pumps, wastewater enters the impeller axially and passes through the volute casing at 90 degrees to its original direction (Figure 3a). This type of pump is appropriate for pumping against low or moderate heads.

**Figure 3a**



Mixed flow pumps are most viable for pumping large quantities of wastewater at low head. In these pumps, the outside diameter of the impeller is less than an ordinary centrifugal pump, increasing flow volume.

**Ventilation**
Ventilation and heating are required if the lift station includes an area routinely entered by personnel. Ventilation is particularly important to prevent the collection of toxic and/or explosive gases. According to the Nation Fire Protection Association (NFPA) Section 820, all continuous ventilation systems should be fitted with flow detection devices connected to alarm systems to indicate ventilation system failure.

Dry-well ventilation codes typically require **six continuous air changes per hour or 30 intermittent air changes per hour. Wet wells typically require 12 continuous air changes per hour or 60 intermittent air changes per hour.**

Motor control center (MCC) rooms should have a ventilation system adequate to provide six air changes per hour and should be air conditioned to between 13 and 32 degrees Celsius (55 to 90 degrees F). If the control room is combined with an MCC room, the temperature should not exceed 30 degrees C or 85 degrees F. All other spaces should be designed for 12 air changes per hour. The minimum temperature should be 13 degrees C (55 degrees F) whenever chemicals are stored or used.

**Odor control**
Odor control is frequently required for lift stations. A relatively simple and widely used odor control alternative is minimizing wet-well turbulence. More effective options include collection of odors generated at the lift station and treating them in scrubbers or biofilters or the addition of odor control chemicals to the sewer upstream of the lift station. Chemicals typically used for odor control include chlorine, hydrogen peroxide, metal salts (ferric chloride and ferrous sulfate) oxygen, air and potassium permanganate. Chemicals should be closely monitored to avoid affecting downstream treatment processes, such as extended aeration.

**Power supply**
The reliability of power for the pump motor drives is a basic design consideration. Commonly used methods of emergency power supply include electric power feed from two independent power distribution lines; an on-site standby generator; an adequate portable generator with quick connection; a stand-by engine driven pump; ready access to a suitable portable pumping unit and appropriate connections; and availability of an adequate holding facility for wastewater storage upstream of the lift station.

**Performance**
The overall performance of a lift station depends on the performance of the pumps. All pumps have four common performance characteristics: capacity, head, power and overall efficiency. Capacity (flow rate) is the quantity of liquid pumped per unit of time, typically measured as gallons per minute (gpm) or million gallons per day (mgd). Head is the energy supplied to the wastewater per unit weight, typically expressed as feet of

water. Power is the energy consumed by a pump per unit time, typically measured as kilowatt-hours. Overall efficiency is the ratio of useful hydraulic work performed to actual work input. Efficiency reflects the pump relative power losses and is usually measured as a percentage of applied power. Pump performance curves are used to define and compare the operating characteristics of a pump and to identify the best combination of performance characteristics under which a lift station pumping system will operate under typical conditions (flows and heads).

Pump systems operate at 75 to 85 percent efficiency most of the time, while overall pump efficiency depends on the type of installed pumps, their control system, and the fluctuation of influent wastewater flow. Performance optimization strategies focus on different ways to match pump operational characteristics with system flow and head requirements.

They may include the following options:
- Adjusting system flow paths,
- Installing variable speed drives,
- Using parallel pumps,
- Installing pumps of different sizes,
- Trimming a pump impeller and
- Putting a two-speed motor on one or more pumps in a lift station.

While savings will vary with the system, electrical energy savings in the range of 20 to 50 percent are possible by optimizing system performance.

**Operation and Maintenance**

Lift station operation is usually automated and does not require continuous on-site operator presence. However, frequent inspections are recommended to ensure normal functioning and to identify potential problems early.

Weekly pump station inspection typically includes observation of the following:

- Pumps, motors and drives for unusual noise, vibration, heating or leakage;
- Check of pump suction and discharge lines for valving arrangement and leakage;
- Check of control panel switches for proper position; monitoring of discharge pump rates and pump speed; and
- Monitoring of pump suction and discharge pressure.

Lift station inspection typically includes observation of pumps, motors and drives for unusual noise, vibration, heating and leakage, check of pump suction and discharge lines for valving arrangement and leakage, check of control panel switches for proper position, monitoring of discharge pump rates and pump speed and monitoring of the pump suction and discharge pressure. Weekly inspections are typically conducted, although the frequency really depends on the size of the lift station.

If a lift station is equipped with grinder bar screens to remove coarse materials from the wastewater, these materials are collected in containers and disposed of to a sanitary landfill site as needed. If the lift station has a scrubber system for odor control, chemicals are supplied and replenished typically every three months. If chemicals are added for odor control ahead of the lift station, the chemical feed stations should be inspected weekly and chemicals replenished as needed.

The most labor-intensive task for lift stations is routine preventive maintenance. A well-planned maintenance program for lift station pumps prevents unnecessary equipment wear and downtime. Lift station operators must maintain an inventory of critical spare parts. The number of spare parts in the inventory depends on the critical needs of the unit, the rate at which the part normally fails and the availability of the part. The operator should tabulate each pumping element in the system and its recommended spare parts. This information is typically available from the operation and maintenance manuals provided with the lift station.

**Costs**
Lift station costs depend on many factors, including;

- Wastewater quality, quantity and projections;
- Zoning and land use planning of the area where the lift station will be located;
- Alternatives for standby power sources;
- Operation and maintenance needs and support;
- Soil properties and underground conditions;
- Required lift to the receiving (discharge) sewer line;
- The severity of impact of accidental sewage spill upon the local area; and
- The need for an odor control system.

These site- and system-specific factors must be examined and incorporated in preparing a lift station cost estimate.

**Construction costs**
The most important factors influencing cost are the design lift station capacity and the installed pump power. Another cost factor is the lift station complexity.

Factors that classify a lift station as complex include two or more of the following:

- Extent of excavation;
- Subsurface condition
- Congested site and/or restricted access;
- Rock excavation;
- Extensive dewatering requirements, such as cofferdams;
- Site conflicts, including modification or removal of existing facilities;
- Special foundations, including piling;
- Dual power supply and on-site switch stations and emergency power generator; and

- High pumping heads (design heads in excess of 200 ft.).

Mechanical, electrical, and control equipment delivered to a pumping station construction site typically account for 15 to 30 percent of total construction costs. Lift station construction has a significant economy-of-scale. Typically, if the capacity of a lift station is increased 100 percent, the construction cost would increase only 50 to 55 percent. An important consideration is that two identical lift stations will cost 25 to 30 percent more than a single station of the same combined capacity. Usually, complex lift stations cost two to three times more than more simple lift stations with no construction complications.

**Operation and Maintenance costs**
Lift station operation and maintenance costs include power, labor, maintenance and chemicals (if used for odor control). Usually, the costs for solids disposal are minimal, but are included if the lift station is equipped with bar screens to remove coarse materials from the wastewater. Typically, power costs account for 85 to 95 percent of the total operation and maintenance costs and are directly proportional to the unit cost of power and the actual power used by the lift station pumps. Labor costs average 1 to 2 percent of total costs. Annual maintenance costs vary, depending on the complexity of the equipment and instrumentation.

**Sanitary sewer lift station maintenance tips**
Performance of routine and preventative maintenance can save the on-site lift station owner from costly repair bills. The following are suggestions that may ensure fewer breakdowns and problems:

- Wet wells should be pumped out and cleaned at least twice a year, or more often if necessary, to prevent solids and grease buildup. Buildup of solids can create odors and damage the pump.
- Inspection of submersible pumps should be performed quarterly. Inspection of the impeller should be performed quarterly or when motor hours are not within 10 percent of each other. The inspections would assure that the impeller is free of debris.
- Inspection of the check valves should be performed at least twice a year to ensure proper working order and to prevent backflow from the force main to the wet well.
- Cleaning and inspections of floats four times a year assure proper performance. The buildup of grease prevents floats from working properly.
- Inspection of the light and alarm systems should be performed weekly. An alarm system in working order can alert you to problems immediately.
- Installation of hour meters on each motor will give one an accurate record of how often each motor is cycling and, hence, the amount of water being pumped through the system. A logbook of motor hours, dates and maintenance performed should be kept.
- Amp readings should be taken at least once a month on each motor in the on-site lift station. If the amp readings do not meet the manufacturer's specifications,

it is an indication that debris is lodged in the propeller within the motor or that water has entered the motor housing or the wiring.
- A semiannual inspection of all electrical motor control equipment to find poor connections and worn parts should be performed.

## FORCE MAINS

### Description

Force mains are pipelines that convey wastewater under pressure from the discharge side of a pump or pneumatic ejector to a discharge point. Pumps or compressors located in a lift station provide the energy for wastewater conveyance in force mains.

The key elements of force mains are:

- Pipe,
- Valves,
- Pressure surge control devices and
- Force main cleaning system.

Force mains are constructed from various materials and come in a wide range of diameters. Wastewater quality governs the selection of the most suitable pipe material. Operating pressure and corrosion resistance also impact the choice. Pipeline size and wall thickness are determined by wastewater flow, operating pressure and trench conditions.

### Common modifications

Force mains may be aerated or the wastewater chlorinated at the pump station to prevent odors and excessive corrosion. Pressure surge control devices are installed to reduce pipeline pressure below a safe operating pressure during lift station start-up and shut-off. Typically, automatically operated valves (cone or ball type) control pressure surges at the pump discharge or pressure surge tanks.

Normally, force main cleaning includes running a manufactured “pigging” device through the line and long force mains are typically equipped with **“pig”** insertion and retrieval stations. In most cases, insertion facilities are located within the lift station and the pig removal station is at the discharge point of the force main. Several launching and retrieval stations are usually provided in long force mains to facilitate cleaning of the pipeline.

### Applicability

Force mains are used to convey wastewater from a lower to higher elevation, particularly, where the elevation of the source is not sufficient for gravity flow and/or the use of gravity conveyance will result in excessive excavation depths and high sewer pipeline construction costs.

Ductile iron and polyvinyl chloride (PVC) are the most frequently used materials for wastewater force mains. Ductile iron pipe has particular advantages in wastewater collection systems due to its high strength and high-flow capacity with greater than nominal inside diameters and tight joints. For special corrosive conditions and extremely high-flow characteristics, polyethylene-lined ductile iron pipe and fittings are widely used.

Cast-iron pipe with glass lining is available in standard pipe sizes, with most joints in lengths up to 6.1 meters (20 feet). Corrosion-resistant plastic-lined piping systems are used for certain waste carrying applications. Polyethylene-lined ductile iron pipe and fittings known as “poly-bond-lined” pipe is widely used for force mains conveying highly corrosive industrial or municipal wastewater. The types of thermoplastic pipe materials used for force main service are PVC, acrylonitrilebutadiene-styrene (ABS) and polyethylene (PE).

The corrosion resistance, light weight, and low hydraulic friction characteristics of these materials offer certain advantages for different force main applications, including resistance to microbial attack. Typically, PVC pipes are available in standard diameters of 100 to 900 mm (4 to 36 inches) and their laying lengths normally range from 3 to 6 meters (10 to 20 feet). The use of composite material pipes, such as fiberglass-reinforced mortar pipe (“truss pipe”), is increasing in the construction of force mains. A truss pipe is constructed on concentric ABS cylinders with annular space filled with cement. Pipe fabricated of fiberglass reinforced epoxy resin is almost as strong as steel, as well as corrosion- and abrasion-resistant.

Certain types of asbestos-cement pipe are applicable in construction of wastewater force mains. The advantage of asbestos-cement pipes in sewer applications is their low hydraulic friction. These pipes are relatively lightweight, allowing long laying lengths in long lines. Asbestos-cement pipes are also highly corrosion resistant. At one time, it was thought that many asbestos-containing products (including asbestos-cement pipe) would be banned by the U.S. Environmental Protection Agency. However, a court ruling overturned this ban and the pipe is available and still used for wastewater force main applications (Sanks, 1998).

Force mains are very reliable when they are properly designed and maintained. In general, force main reliability and useful life are comparable to that of gravity sewer lines, but pipeline reliability may be compromised by excessive pressure surges, corrosion or lack of routine maintenance.

**Advantages**

Use of force mains can significantly reduce the size and depth of sewer lines and decrease the overall costs of sewer system construction. Typically, when gravity sewers are installed in trenches deeper than 6.1 meters (20 feet), the cost of sewer line installation increases significantly because more complex and costly excavation equipment and trench-shoring techniques are required. Usually, the diameter of pressurized force mains is one to two sizes smaller than the diameter of gravity sewer lines conveying the same flow, allowing significant pipeline cost reduction. Force main installation is simple because of shallower pipeline trenches and reduced quantity of earthwork. Installation of force mains is not dependent on site-specific topographic conditions and is not impacted by available terrain slope, which typically limits gravity wastewater conveyance.

**Disadvantages**
While construction of force mains is less expensive than gravity sewer lines for the same flow, force main wastewater conveyance requires the construction and operation of one or more lift stations. Wastewater pumping and use of force mains could be eliminated or reduced by selecting alternative sewer routes, consolidating a proposed lift station with an existing lift station or extending a gravity sewer, using directional drilling or other state-of-the art deep excavation methods.

The dissolved oxygen content of the wastewater is often depleted in the wet well of the lift station, and its subsequent passage through the force main results in the discharge of septic wastewater, which not only lacks oxygen, but often contains sulfides. Frequent cleaning and maintenance of force mains is required to remove solids and grease buildup and minimize corrosion due to the high concentration of sulfides.

Pressure surges are abrupt increases in operating pressure in force mains, which typically occur during pump start-up and shut-off. Pressure surges may have negative effects on force main integrity, but can be reduced by proper pump station and pipeline design.

**Design criteria**
Force main design is typically integrated with lift station design. The major factors to consider in analyzing force main materials and hydraulics include the design formula for sizing the pipe, friction losses, pressure surges and maintenance. The Hazen-Williams formula is recommended for the design of force mains. This formula includes a roughness coefficient C, which accounts for pipeline hydraulic friction characteristics. The roughness coefficient varies with pipe material, size and age.

**Force main pipe materials**
Selection criteria for force main pipe materials include:

- Wastewater quantity, quality and pressure;
- Pipe properties, such as strength, ease of handling and corrosion resistance;
- Availability of appropriate sizes, wall thickness and fittings;
- Hydraulic friction characteristics and
- Cost.

Ductile iron pipe offers strength, stiffness, ductility and a range of sizes and thicknesses and is the typical choice for high-pressure and exposed piping. Plastic pipe is most widely used in short force mains and smaller diameters.

Table 1 lists the types of pipe recommended for use in a force main system and suggested applications.

**Table 1 - Characteristics of common force main pipe materials**

| Material | Application | Advantages | Disadvantages |
|---|---|---|---|
| Cast or Ductile Iron, | High pressure<br>Available in 4-54 in | Good resistance to pressure surges | More expensive than concrete and fiberglass |
| Steel Cement-Lined | High pressure<br>All pipe sizes | Excellent resistance to pressure surges | More expensive than concrete and fiberglass |
| Asbestos Cement | Moderate pressure<br>For 36-inch + pipe | No corrosion<br>Slow grease buildup | Relatively brittle |
| Fiberglass-Reinforced Epoxy Pipe | Moderate pressure<br>For up to 36-inch pipe | No corrosion<br>Slow grease buildup | 350 psi max pressure |
| Plastic | Low pressure<br>For up to 36-inch pipe | No corrosion<br>Slow grease buildup | Suitable for small pipe sizes and low pressure |

**Velocity**

Force mains from the lift station are typically **designed for velocities** between 0.6 to 2.4 meters per second **(2 to 8 feet per second**). Such velocities are normally based on the most economical pipe diameters and typical available heads.

For shorter force mains (less than 610 meters or 2,000 feet) and low lift requirements (less than 9.1 meters or 30 feet), the recommended design force main velocity range is 1.8 to 2.7 meters per second (6 to 9 feet per second). This higher design velocity allows the use of smaller pipe, reducing construction costs. Higher velocity also increases pipeline friction loss by more than 50 percent, resulting in increased energy costs. To reduce the velocity, a reducer pipe or a pipe valve can be used. Reducer pipes are often used because of the costly nature of pipe valves. These reducer pipes, which are larger in diameter, help to disperse the flow, therefore reducing the velocity.

**The maximum force main velocity at peak conditions** is recommended not to exceed 3 meters per second **(10 feet per second)**. Table 2 provides examples of force main capacities at various pipeline sizes, materials and velocities. The flow volumes may vary depending on the pipe material used.

**Table 2 - Force main capacity**

| Diameter Inches | 2 fps GPM | 4 fps GPM | 6 fps GPM |
|---|---|---|---|
| 6 | 176 | 362 | 528 |
| 8 | 313 | 626 | 1,252 |
| 10 | 490 | 980 | 1,470 |
| 18 | 1,585 | 3,170 | 4,755 |
| 24 | 2,819 | 5,638 | 8,457 |
| 36 | 6,342 | 12,684 | 19,026 |

**Vertical alignment**
Force mains should be designed so that they are always full and pressure in the pipe is greater than 69 kilo-Pascals (10 pounds per square inch) to prevent the release of gases. Low and high points in the vertical alignment should be avoided; considerable effort and expense are justified to maintain an uphill slope from the lift station to the discharge point. High points in force mains trap air, which reduces available pipe area, causes non-uniform flow, and creates the potential for sulfide corrosion. Gas relief and vacuum valves are often installed if high points in the alignment of force mains cannot be avoided, while blow-offs are installed at low points.

**Pressure surges**
The possibility of sudden changes in pressure (pressure surges) in the force main due to starting and/or stopping pumps (or operation of valves appurtenant to a pump) must be considered during design. The duration of such pressure surges ranges between 2 to 15 seconds. Each surge is site-specific and depends on pipeline profile, flow, change in velocity, inertia of the pumping equipment, valve characteristics, pipeline materials and pipeline accessories. Critical surges may be caused by power failure. If pressure surge is a concern, the force main should be designed to withstand calculated maximum surge pressures.

**Valves**
Valves are installed to regulate wastewater flow and pressure in the force mains. Valves can be used to stop and start flow, control the flow rate, divert the flow, prevent backflow, and control and relieve the pressure. The number, type and location of force main valves depend on the operating pressures and potential surge conditions in the pipeline. Although valves have a lot of benefits, the costliness of them prevents them from being used extensively.

**Performance**
Force main performance is closely tied to the performance of the lift station to which it is connected. Pump-force main performance curves are used to define and compare the operating characteristics of a given pump or set of pumps along with the associated force main. They are also used to identify the best combination of performance characteristics under which the lift station-force main system will operate under typical conditions (flows and pressures). Properly designed pump-force main systems usually

allow the lift station pumps to operate at 35 to 55 percent efficiency most of the time. Overall pump efficiency depends on the type of pumps, their control system and the fluctuation of the influent wastewater flow.

**Operation and Maintenance**

The operation of force main-lift station systems is usually automated and does not require continuous on-site operator presence. However, annual force main route inspections are recommended to ensure normal functioning and to identify potential problems.

Special attention is given to the integrity of the force main surface and pipeline connections, unusual noise, vibration, pipe and pipe joint leakage and displacement, valving arrangement and leakage, lift station operation and performance, discharge pump rates and pump speed and pump suction and discharge pressures. Depending on the overall performance of the lift station-force main system, the extent of grease buildup and the need for pipeline pigging are also assessed.

If there is an excessive increase in pump head and the head loss increase is caused by grease buildup, the pipeline is pigged. Corrosion is rarely a problem since pipes are primarily constructed of ductile iron or plastic, which are highly resistant to corrosion. Buildup can be removed by pigging the pipeline.

**Costs**

Force main costs depend on many factors including:

- Conveyed wastewater quantity and quality,
- Force main length,
- Operating pressure,
- Soil properties and underground conditions,
- Pipeline trench depth,
- Appurtenances, such as valves and blow offs, and
- Community impacts.

These site- and system-specific factors must be examined and incorporated in the preparation of force main cost estimates.

**Construction costs**

Unit force main construction costs are usually expressed in dollars per linear foot of installed pipeline and costs typically include labor and the equipment and materials required for pipeline installation. Table 3 shows unit pipeline construction costs for ductile iron and plastic (PVC) pipes used for force main construction.

These costs are base installation costs and do not include the following:

- General contractor overhead and profit;
- Engineering and construction management;
- Land or right-of-way acquisition;
- Legal, fiscal, and administrative costs;

- Interest during construction; and
- Community impacts.

**Table 3**

| Pipe diameter inches | Ductile Iron $ linear ft | PVC pressure pipe $ linear ft |
|---|---|---|
| 8 | 30.50 | 20.00 |
| 10 | 38.50 | 26.60 |
| 12 | 48.00 | 34.50 |
| 14 | 61.00 | 44.00 |
| 16 | 70.50 | 54.50 |
| 18 | 88.00 | 64.00 |
| 20 | 95.00 | 75.00 |
| 24 | 112.00 | 86.50 |
| 30 | 190.00 | 120.00 |
| 36 | 252.50 | 179.50 |

All unit pipeline costs are adjusted to 2009 dollars.

**Operation and Maintenance costs**

Force main operation and maintenance costs include labor and maintenance requirements. Typically, labor costs account for 85 to 95 percent of total operation and maintenance costs and are dependent on the force main length. The maintenance costs usually vary from $9 to $26/meter ($3 to $8/linear foot), depending on the size and number of appurtenances installed on the force main. An internal inspection using TV equipment can be completed, if visual inspection is not sufficient. TV inspection can be costly, ranging from $1,300 to $15,250 per mile, with an average cost of $6,120 per mile.

## PRESSURE SEWER SYSTEMS

**Applicability**

Pressure sewer systems are most cost-effective where housing density is low, where the terrain has undulations with relatively high relief and where the system outfall must be at the same or a higher elevation than most or all of the service area. They can also be effective where flat terrain is combined with high groundwater or bedrock, making deep cuts and/or multiple lift stations excessively expensive. They can be cost-effective, even in densely populated areas where difficult construction or right-of-way conditions exist or where the terrain will not accommodate gravity sewers.

Since pressure systems do not have the large excess capacity typical of conventional gravity sewers, they must be designed with a balanced approach, keeping future growth and internal hydraulic performance in mind.

**Advantages**

- Pressure sewer systems that connect several residences to a “cluster” pump station can be less expensive than conventional gravity systems. On-property facilities represent a major portion of the capital cost of the entire system and are shared in a cluster arrangement.
- This can be an economic advantage since on-property components are not required until a house is constructed and are borne by the homeowner. Low front-end investment makes the present-value cost of the entire system lower than that of conventional gravity sewerage, especially in new development areas where homes are built over many years.
- Because wastewater is pumped under pressure, gravity flow is not necessary and the strict alignment and slope restrictions for conventional gravity sewers can be relaxed. Network layout does not depend on ground contours: pipes can be laid in any location and extensions can be made in the street right-of-way at a relatively small cost without damage to existing structures.

Other advantages of pressure sewers include:

- Material and trenching costs are significantly lower because pipe size and depth requirements are reduced.
- Low-cost clean outs and valve assemblies are used rather than manholes and may be spaced further apart than manholes in a conventional system.
- Infiltration is reduced, resulting in reductions in pipe size.
- The user pays for the electricity to operate the pump unit. The resulting increase in electric bills is small and may replace municipality or community bills for central pumping eliminated by the pressure system.
- Final treatment may be substantially reduced in hydraulic and organic loading in septic tank effluent pump systems. Hydraulic loadings are also reduced for grinder pump systems.
- Because sewage is transported under pressure, more flexibility is allowed in sighting final treatment facilities and may help reduce the length of outfall lines or treatment plant construction costs.

**Disadvantages**

- Requires much institutional involvement because the pressure system has many mechanical components throughout the service area.
- The operation and maintenance (O&M) cost for a pressure system is often higher than a conventional gravity system due to the high number of pumps in use. However, lift stations in a conventional gravity sewer can reverse this situation.
- Annual preventive maintenance calls are usually scheduled for grinder pump (GP) components of pressure sewers. Septic tank effluent pump (STEP) systems also require a pump out of septic tanks at two- to three-year intervals.
- Public education is necessary so the user knows how to deal with emergencies and how to avoid blockages or other maintenance problems.
- The number of pumps that can share the same downstream force main is limited.
- Power outages can result in overflows if standby generators are not available.
- Life-cycle replacement costs are expected to be higher because pressure sewers have a lower life expectancy than conventional systems.

- Odors and corrosion are potential problems because the wastewater in the collection sewers is usually septic. Proper ventilation and odor control must be provided in the design and non-corrosive components should be used.
- Air release valves are often vented to soil beds to minimize odor problems, and special discharge and treatment designs are required to avoid terminal discharge problems.

**Design criteria**
Many different design flows can be used in pressure systems. When positive displacement GP units are used, the design flow is obtained by multiplying the pump discharge by the maximum number of pumps expected to be operating simultaneously. No allowances for infiltration and inflow are required. No minimum velocity is generally used in design, but GP systems must attain three to five feet per second at least once per day.

Pressure mains generally use 50 mm (2 inch) or larger PVC pipe (SDR 21) and rubber-ring joints or solvent welding to assemble the pipe joints. High-density polyethylene (HDPE) pipe with fused joints is widely used in Canada. Electrical requirements, especially for GP systems, may necessitate rewiring and electrical service upgrading in the service area. Pipes are generally buried to at least the winter frost penetration depth; in far northern sites insulated and heat-traced pipes are generally buried at a minimal depth. GP and STEP pumps are sized to accommodate the hydraulic grade requirements of the system**. Discharge points must use drop inlets to minimize odors and corrosion.** Air release valves are placed at high points in the sewer and often are vented to soil beds. Both STEP and GP systems can be assumed to be anaerobic and potentially odorous if subjected to turbulence (stripping of gases such as H2S).

**Operation and Maintenance**
Routine operation and maintenance requirements for both STEP and GP systems are minimal. Most system maintenance activities involve responding to homeowner service calls usually for electrical control problems or pump blockages. STEP systems also require pumping every two to three years.

The inherent septic nature of wastewater in pressure sewers requires that system personnel take appropriate safety precautions when performing maintenance to minimize exposure to toxic gases, such as hydrogen sulfide, which may be present in the sewer lines, pump vaults or septic tanks. Odor problems may develop in pressure sewer systems because of improper house venting. The addition of strong oxidizing agents, such as chlorine or hydrogen peroxide, may be necessary to control odor where venting is not the cause of the problem.

Generally, it is in the best interest of the municipality and the homeowners to have the municipality or sewer utility be responsible for maintaining all system components. General easement agreements are needed to permit access to on-site components, such as septic tanks, STEP units or GP units on private property.

## Costs

Pressure sewers are generally more cost-effective than conventional gravity sewers in rural areas because capital costs for pressure sewers are generally lower than for gravity sewers. While capital cost savings of 90 percent have been achieved, no universal statement of savings is possible because each site and system is unique.

Table 1 presents data from evaluations of the costs of pressure sewer mains and appurtenances (essentially the same for GP and STEP), including items specific to each type of pressure sewer. Purchasing pumping stations in volume may reduce costs by up to 50 percent. The linear cost of mains can vary by a factor of two to three, depending on the type of trenching equipment and local costs of high-quality backfill and pipe. The local geology and utility systems will impact the installation cost of either system.

The homeowner is responsible for energy costs, which will vary from $2.00 to $5.00/month for GP systems, depending on the horsepower of the unit. STEP units generally cost less than $2.00/month.

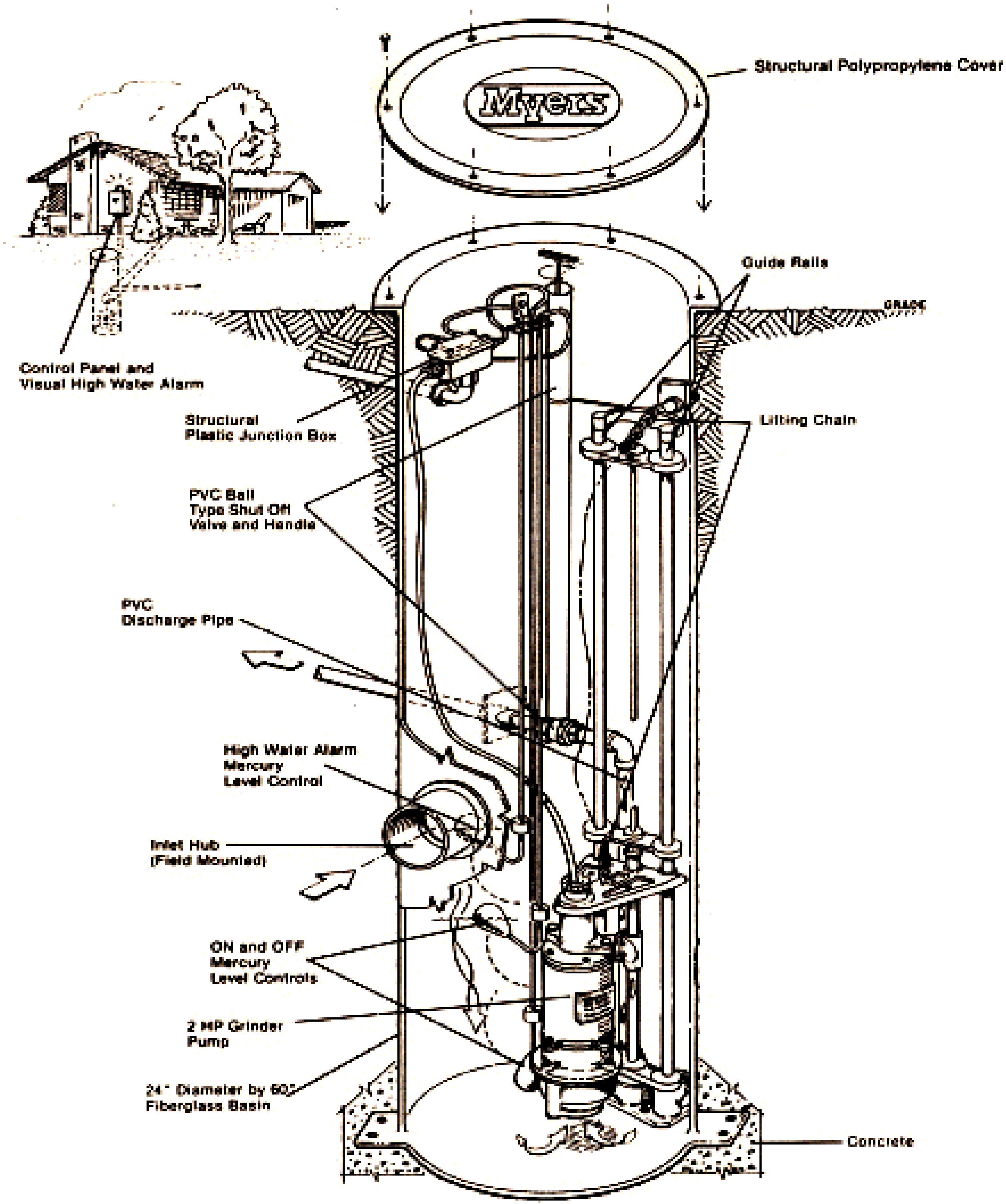
Preventive maintenance should be performed annually for each unit, with monthly maintenance of other mechanical components. STEP systems require periodic pumping of septic tanks. Total <u>O&M costs</u> [What is this? It should probably be spelled out.] average $200-500 per year per unit, and include costs for troubleshooting, inspection of new installations and responding to problems. Mean time between service calls data varies greatly, but values of 4 to 10 years for both GP and STEP units are reasonable estimates for quality installations.

**Table 1 - Average installed unit costs for pressure sewer**

**Mains and appurtenances**

| **Item** | **Unit Cost** | **($) (based on 2009 data)** |
|---|---|---|
| 2-inch mains | $14.75 | L/Ft |
| 3-inch mains | $15.60 | L/Ft |
| 4-inch mains | $17.62 | L/Ft |
| 6-inch mains | $24.80 | L/Ft |
| 8-inch mains | $27.61 | L/Ft |
| Extra for mains in asphalt concrete Pavement | $9.82 | L/Ft |
| 2-inch isolation valves | $494.25 | Each |
| 3-inch isolation valves | $541.30 | Each |
| 4-inch isolation valves | $690.35 | Each |
| 6-inch isolation valves | $785.00 | Each |
| 8-inch isolation valves | $1,130.00 | Each |
| Individual grinder pump | $2,365 | Each |
| Single package pump system | $8,065 | Each |
| Package installation | $1,880-2950 | Each |
| Automatic air release stations | $1,970 | Each |

## Typical grinder pump station



## INSPECTION AND CLEANING

As sewer system networks age, the risk of deterioration, blockages and collapses becomes a major concern. As a result, municipalities worldwide are taking proactive measures to improve performance levels of their sewer systems. Cleaning and inspecting sewer lines are essential to maintaining a properly functioning system; these activities further a community's reinvestment into its wastewater infrastructure.

**Inspection techniques**
Inspection programs are required to determine current sewer conditions and to aid in planning a maintenance strategy. Ideally, sewer line inspections need to take place during low-flow conditions. If the flow conditions can potentially overtop the camera, then the inspection should be performed during low flow to reduce the flow.

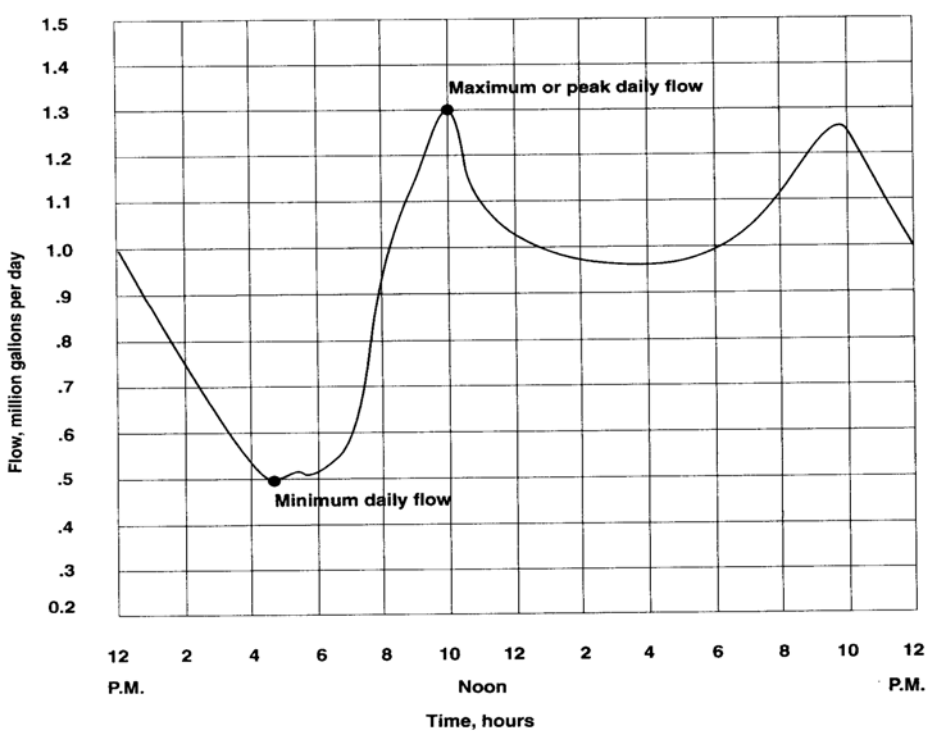



*Fig. 3.1 Variations of dry weather wastewater flow from a typical community*

Most sewer lines are inspected using one or more of the following techniques:

- Closed-circuit television (CCTV).
- Cameras.
- Visual inspection.
- Lamping inspection.

Television (TV) inspections are the most frequently used, most cost-efficient in the long term and most effective method to inspect the internal condition of a sewer. CCTV inspections are recommended for sewer lines with diameters of 0.1-1.2 m (4-48 inches.). The CCTV camera must be assembled to keep the lens as close as possible to the center of the pipe.

In larger sewers, the camera and lights are attached to a raft, which is floated through the sewer from one manhole to the next. To see details of the sewer walls, the camera and lights swivel both vertically and horizontally. In smaller sewers, the cable and camera are attached to a sled, to which a parachute or drogue is attached and floated from one manhole to the next.

Documentation of inspections is very critical to a successful operation and maintenance (O&M) program. CCTV inspections produce a video record of the inspection that can be used for future reference.

In larger sewers where the surface access points are more than 300m (1000 linear feet) apart, camera inspections are commonly performed. This technique involves a raft-mounted film camera and strobe light. This method requires less power than the CCTV, so the power cable is smaller and more manageable. Inspections using a camera are documented on Polaroid still photographs that are referenced in a log book, according to date, time, and location.

Visual inspections are vital in fully understanding the condition of a sewer system. Visual inspections of manholes and pipelines are comprised of surface and internal inspections. Operators should pay specific attention to sunken areas in the groundcover above a sewer line and areas with ponding water. In addition, inspectors should thoroughly check the physical conditions of stream crossings, the conditions of manhole frames and covers or any exposed brickwork, and the visibility of manholes and other structures.

For large sewer lines, a walk-through or internal inspection is recommended. This inspection requires the operator to enter a manhole, the channel, and the pipeline, and assess the condition of the manhole frame, cover and chimney, and the sewer walls above the flow line.

When entering a manhole or sewer line, it is very important to observe the latest Occupational Safety and Health Administration confined space regulations. If entering the manhole is not feasible, mirrors can be used. Mirrors are usually placed at two adjacent manholes to reflect the interior of the sewer line. Lamping inspections are commonly used in low-priority pipes, which tend to be pipes that are less than 20 years old. Lamping is also commonly used on projects where funds are extremely limited. In the lamping technique, a camera is inserted and lowered into a maintenance hole and then positioned at the center of the junction of a manhole frame and the sewer. Visual images of the pipe interior are then recorded with the camera.

**Cleaning techniques**

To maintain its proper function, a sewer system needs a cleaning schedule. There are several traditional cleaning techniques used to clear blockages and to act as preventative maintenance tools. When cleaning sewer lines, local communities need to be aware of EPA regulations on solid and hazardous waste, as defined in 40 CFR 261. In order to comply with state guidelines on testing and disposal of hazardous waste, check with the local authorities.

Table 1 summarizes some of the most commonly used methods to clean sewer systems.

**Table 1**

| Technology | Uses and applications |
|---|---|
| **Mechanical** | |
| Rodding | • Uses an engine and a drive unit with continuous rods or sectional rods.<br>• As blades rotate they break up grease deposits, cut roots, and loosen debris.<br>• Rodders also help thread the cables used for TV inspections and bucket machines.<br>• Most effective in lines up to 300 mm (12 inches) in diameter. |
| Bucket Machine | • Cylindrical device, closed on one end with 2 opposing hinged jaws at the other.<br>• Jaws open and scrape off the material and deposit it in the bucket.<br>• Partially removes large deposits of silt, sand, gravel and some types of solid waste. |
| **Hydraulic** | |
| Balling | • A threaded rubber cleaning ball that spins and scrubs the pipe interior as flow increases in the sewer line.<br>• Removes deposits of settled inorganic material and grease buildup.<br>• Most effective in sewers ranging in size from 13-60 cm (5-24 inches). |
| Flushing | • Introduces a heavy flow of water into the line at a manhole.<br>• Removes floatables and some sand and grit.<br>• Most effective when used in combination with other mechanical operations, such as rodding or bucket machine cleaning. |
| Jetting | • Directs high velocities of water against pipe walls.<br>• Removes debris and grease buildup, clears blockages and cuts roots within small diameter pipes. |

| | |
|---|---|
| | • Efficient for routine cleaning of small-diameter, low-flow sewers. |
| Scooter | • Round, rubber-rimmed, hinged metal shield that is mounted on a steel framework on small wheels. The shield works as a plug to build a head of water.<br>• Scours the inner walls of the pipe lines.<br>• Effective in removing heavy debris and cleaning grease from line. |
| Kites, Bags, and Poly Pigs | • Similar in function to the ball.<br>• Rigid rims on bag and kite induce a scouring action.<br>• Effective in moving accumulations of decayed debris and grease downstream. |
| Silt Traps | • Collect sediments at convenient locations.<br>• Must be emptied on a regular basis as part of the maintenance program. |
| Grease Traps and Sand/Oil Interceptors | • The ultimate solution to grease buildup is to trap and remove it.<br>• These devices are required by some uniform building codes and/or sewer-use ordinances.<br>• Typically, sand/oil interceptors are required for automotive business discharge.<br>• Need to be thoroughly cleaned to function properly.<br>• Cleaning frequency varies from twice a month to once every six months, depending on the amount of grease in the discharge.<br>• Need to educate restaurant and automobile businesses about the need to maintain these traps. |
| Chemicals [1] | • Used to control roots, grease, odors (H2S gas), concrete corrosion, rodents and insects.<br>• *Root Control* – longer-lasting effects than power rodder (approximately 2-5 years).<br>• *H2S gas* - some common chemicals used are chlorine (Cl2), hydrogen peroxide (H2O2), pure oxygen (O2), air, lime (Ca(OH2)), sodium hydroxide (NaOH) and iron salts.<br>• *Grease and soap problems*—some common chemicals used are bioacids, digester, enzymes, bacteria cultures, catalysts, caustics, hydroxides and neutralizers. |

[1] *Before using these chemicals review the Material Safety Data Sheets (MSDS) and consult the local authorities on the proper use of chemicals as per local ordinance and the proper disposal of the chemicals used in the operation. If assistance or guidance is needed regarding the application of certain chemicals, contact the U.S. EPA or state water pollution control agency.*

In recent years, new methodologies and accelerated programs have been developed to take advantage of the information obtained from sewer line maintenance operations.

Such programs incorporate information gathered from various maintenance activities with basic sewer evaluations to create a system that can remedy and prevent future malfunctions and failures more effectively and efficiently. A study performed by the American Society of Civil Engineers reports that the most important maintenance activities are cleaning and CCTV inspections. Table 2 shows the average frequency of various maintenance activities.

**Table 2**

| **Activity** | **Average ( % of system per year)** |
|---|---|
| Cleaning | 29.9 |
| Root removal | 2.9 |
| Manhole inspection | 19.8 |
| CCTV inspection | 6.8 |
| Smoke testing | 7.8 |

A maintenance plan attempts to develop a strategy and priority for maintaining pipes based on several of the following factors:

- Problems—frequency and location; 80 percent of problems occur in 25 percent of the system (Hardin and Messer, 1997).
- Age—older systems have a greater risk of deterioration than newly constructed sewers.
- Construction material—pipes constructed of materials that are susceptible to corrosion have a greater potential of deterioration and potential collapse.
- Non-reinforced concrete pipes, brick pipes and asbestos cement pipes are examples of pipes susceptible to corrosion.
- Pipe diameter/volume conveyed—pipes that carry larger volumes take precedence over pipes that carry a smaller volume.
- Location—pipes located on shallow slopes or in flood-prone areas have a higher priority.
- Force main vs. gravity-force mains have a higher priority than gravity, size for size, due to the complexity of the cleaning and repairs.
- Subsurface conditions—depth to groundwater, depth to bedrock, soil properties (classification, strength, porosity, compressibility, frost susceptibility, erodibility and pH).
- Corrosion potential—Hydrogen Sulfide (H2S) is responsible for corroding sewers, structures and equipment used in wastewater collection systems. The interior conditions of the pipes need to be monitored and treatment needs to be implemented to prevent the growth of slime bacteria and the production of H2S gases.

**Advantages and Disadvantages**

The limitations of various inspection techniques used by sanitary sewer authorities are summarized in Table 3.

**Table 3**

| Inspection technique | Limitations |
|---|---|
| Visual Inspection | In smaller sewers, the scope of problems detected is minimal because the only portion of the sewer that can be seen in detail in near the manhole. Therefore, any definitive information on cracks or other structural problems is unlikely. However, this method does provide information needed to make decisions on rehabilitation. |
| Camera Inspection | When performing a camera inspection in a large-diameter sewer, the inspection crew is essentially taking photographs haphazardly, and as a result, the photographs tend to be less comprehensive. |
| Closed Circuit Television (CCTV) | This method requires late-night inspection, and as a result, the TV operators are vulnerable to lapses in concentration. CCTV inspections are also quire expensive and time consuming. |
| Lamping Inspection | The video camera does not fit into the pipe, and during the inspection it remains only in the maintenance hole. As a result, only the first 10 feet of the pipe can be viewed or inspected using this method. |

Table 4 shows the limitations of some of the cleaning methods used by sanitary sewer authorities.

**Table 4**

| **Cleaning methods** | **Limitations** |
|---|---|
| 1. Balling<br><br>2. Jetting<br><br>3. Scooter | In general, these methods are only successful when necessary water pressure or head is maintained without flooding basements or houses at low elevations.<br>1. Balling - Balling cannot be used effectively in pipes with bad offset joints or protruding service connections because the ball can become distorted.<br>2. Jetting - The main limitation of this technique is that cautions need to be used in areas with basement fixtures and in steep-grade hill areas<br>3. Scooter - When cleaning larger lines, the manholes need to be designed to a larger size in order to receive and retrieve the equipment. Otherwise, the scooter needs to be assembled in the manhole.<br>Caution also needs to be used in areas with basement fixtures and in steep-grade hill areas. |
| Bucket Machine | This device has been known to damage sewers.<br>The bucket machine cannot be used when the line is completely plugged because this prevents the cable from being threaded from one manhole to the next. Set-up of this equipment is time-consuming. |
| Flushing | This method is not very effective in removing heavy solids. Flushing does not remedy this problem because it only achieves temporary movement of debris from one section to another in the system. |
| High-Velocity Cleaner | The efficiency and effectiveness of removing debris by this method decreases as the cross-sectional areas of the pipe increase. Backups into residences have been known to occur when this method has been used by inexperienced operators. Even experienced operators require extra time to clear pipes of roots and grease. |
| Kite or Bag | When using this method, use caution in locations with basement fixtures and steep-grade hill areas. |
| Rodding | Continuous rods are harder to retrieve and repair if broken and they are not useful in lines with a diameter of greater than 300 mm (0.984 feet) because the rods have a tendency to coil and bend. This device also does not effectively remove sand or grit, but may only loosen the material to be flushed out at a later time. |

The primary benefit of implementing a sewer maintenance program is the reduction of SSOs, basement backups, and other releases of wastewater from the collection system due to substandard sewer conditions. Improper handling of instruments and chemicals used in inspecting and maintaining sewer lines may cause environmental harm.
Examples include:

- Improperly disposing of collected materials and chemicals from cleaning operations.
- Improperly handling chemical powdered dyes.
- Inadequately maintaining inspection devices.
- Some instruments have a tendency to become coated with petroleum-based residues and if not handled properly they can become a fire hazard.

**Performance**
Table 5 defines the conditions under which certain cleaning methods are most effective.

**Table 5**
***A = Best D = Not best***

| Solution | Emergency Stoppage | Grease | Roots | Sand, Grit, Debris | Odors |
|---|---|---|---|---|---|
| Balling | | B | | B | C |
| High-Velocity Cleaning | D | A | | B | C |
| Flushing | | | | | C |
| Sewer Scooter | | C | | C | |
| Bucket Machine | | | | C | |
| Power Rodder | B | D | C | | |
| Hand Rodding | B | D | C | | |
| Chemicals | | C | B | | B |

Cleaning is an important part of pipe maintenance. Sewer line cleaning is prioritized based on the age of the pipe and the frequency of the problems within it. The system may use rodding and pressurized cleaning methods to maintain the pipes. Bucket machines are rarely used because cleaning by this method tends to be time-consuming.

The system may use mechanical, rather than chemical, methods to remove grease and roots. Introducing chemicals into the cleaning program requires hiring an expert crew, adopting a new program and instituting a detention time to ensure the chemicals' effectiveness.

Recordkeeping is also vital to the success of such a maintenance program. The system may start tracking the number of times the sewer lines were inspected and cleaned and the number of overflows and backups a sewer line experienced. This information will help the utility reprioritize sewer line maintenance and adapt a more appropriate time schedule for cleaning and inspecting the sewer lines.

**Costs**
Table 6 summarizes the annual maintenance costs per mile for cleaning and inspecting.

**Table 6**

| Identifier | Range of cost 2009$ | Average cost (based on 2009 data) |
|---|---|---|
| Total O&M cost/mile/year | $1,263 - $62,474 | $3,755 |
| Labor (cost/mile/year) | $924 - $26,375 | $4,823 |
| Fringe Benefits (cost/mile/year) | $255 - $12,013 | $1,576 |
| Chemicals (cost/mile/year) | $.04 - $10,130 | $681 |
| Hydroflush Cleaning (cost/mile) | $631 - $6,956 | $2,261 |
| Television Inspection (cost/mile) | $1,330 - $15,228 | $6,118 |

## HAZARDS

Wastewater collection system operators are exposed daily to numerous health risks. These risks include exposure to gases, chemicals, endotoxins, exotoxins and pathogens. Asphyxiating, irritating and toxic gases produced through the anaerobic degradation of carbonaceous wastes include ammonia ($NH_3$), carbon dioxide ($CO_2$), carbon monoxide (CO), hydrogen sulfide ($H_2S$) and methane ($CH_4$). In addition to these gases, chemicals such as vaporized, volatile organic compounds (VOCs) from wastewater, also represent a health risk.

Dead and living bacterial cells release endotoxins and exotoxins, respectively. These toxins attack cells and tissues in the human body and cause gastrointestinal, respiratory tract and nervous system diseases. Examples of several diseases caused by exotoxins include anthrax, food poisoning and tetanus. Of all health risks associated with wastewater treatment facilities, perhaps disease transmission is of most concern to wastewater operators.

Pathogens include viruses, bacteria, fungi, protozoa and helminthes (or worms). Exposure to pathogens and the potential for disease transmission through contact with pathogen-contaminated wastewater, aerosols, compost, foam, sludge and work surfaces are considered to be risks for wastewater personnel.

Pathogens enter wastewater treatment facilities from the bodily wastes of infected individuals, which may be human, domestic animals or wild animals. Fecal waste and urine from cats and dogs enter wastewater treatment facilities through inflow and infiltration (I/I). Slaughterhouse waste from poultry, pork and beef industries also contains many pathogens that are capable of infecting humans. Fecal waste and urine from rodents in the sanitary and combined sewers represent sources of pathogens.

Viruses are ultramicroscopic agents and are inert. They are not capable of independent growth or reproduction and are not considered to be living organisms. Viruses increase in number through replication. For replication to occur, a virus must enter a living cell (host) and cause disease. Although numerous viral groups are present in wastewater, the principle viruses of concern include the enteroviruses and the hepatitis viral group. Enteroviruses attack the gastrointestinal tract, while hepatitis viruses attack the liver.

Bacteria are simple, unicellular organisms. Most bacteria range in size from 0.1 micrometers (µm) to 15 µm, and the shape of most bacteria is rod (bacillus), spherical (coccus) or spiral (sprillium). Bacteria are ubiquitous in nature, and most are harmless. They reproduce asexually, usually by splitting in half, and may be found as individual cells, clusters of cells or chains of cells (filaments).

There are two types of pathogenic bacteria. "True" pathogens, such as *Leptospira interrogans,* are aggressive and cause disease. "Opportunistic" pathogens, such as *Escherichia coli,* are typically found on or in the human body and do not cause disease unless the body's immune system is weakened by injury, a "true" pathogen or physiological disease

Fungi are a diverse group of organisms. Some fungi, such as yeast, are unicellular, while other fungi such as molds and mushrooms are multicellular. Fungi are saprophytes and obtain their nourishment from dead, organic matter or living organisms. Although there are few pathogenic fungi, these fungi are not obligate parasites.

Protozoa are single-celled organisms that are animal-like, fungus-like or plant-like. Protozoa often are grouped or identified by their ability or lack of ability for locomotion. Some protozoa move by the beating action of hair-like structures or cilia (ciliates) or whip-like structures or flagella (flagellates). Some protozoa (amoebae) move by a pseudopodia action, i.e., a streaming of the cytoplasm or intracellular content against the cell membrane.

Most protozoa are free-living, but several parasitic ciliated, flagellated, and amoeboid protozoa are found in wastewater. Of these parasitic protozoa, two protozoa are of concern to wastewater personnel. These protozoa are *Crytosporidium parvum* and *Giardia lamblia*. These organisms infest the intestinal tract and cause profuse and watery diarrhea.

| Group | Pathogens |
|---|---|
| Viruses | Enterovirus, Hepatitis viral group |
| Bacteria | *Campylobacter jejuni, Leptospira interrogans* |
| Fungi | *Aspergillus fumigatus* |
| Protozoa | *Giardia lamblia* |

Pathogens that enter wastewater treatment facilities come from a variety of sources including infected community members, domestic animals and wild animals. Infected community members may display acute or chronic symptoms of disease or may display no disease symptoms (asymptomatic). Regardless of disease manifestation (symptoms), infected individuals release pathogens in their bodily wastes. Travelers and military personnel, as well as **migrant workers,** represent an additional risk of the introduction of a new pathogen to the wastewater treatment facility.

In order for a wastewater worker to become infected with a pathogen, three steps in disease transmission must be satisfied. First, the pathogen must leave an infected individual within the community. Second, the pathogen must come in contact with a worker; and third, the pathogens must enter the worker.

There are three common routes of entrance or portals of entry for pathogens. These routes are ingestion (fecal-oral), inhalation and invasion. The most common route of entrance is ingestion. For an infection to occur in a new individual, an adequate number of viable pathogens must enter the individual and overcome the individual's bodily defenses. Regardless of the risk assigned for disease transmission from any pathogen, that risk can be significantly decreased or eliminated through the use of proper hygiene measures, protective equipment and common sense.

The use of proper hygiene measures, protective equipment and common sense prevent contact with pathogens or block their portals of entry. These measures prevent infection. Measures available to wastewater personnel to prevent infection include the use of antimicrobial agents, automation, cleanliness and consumption precautions and restrictions, first aid, proper sampling practices, protective clothing, records, training and ventilation. In addition to these measures, the use of immunobiologicals (vaccines and immunizations) also helps to prevent pathogen infection.

| **Cleanliness and Consumption Precautions and Restrictions** |
|---|
| Avoid touching the ears, eyes, mouth and nose with your hands, unless you have just washed. |
| Confine eating, drinking, smoking and the use of smokeless tobacco products to designated areas. |
| Keep your fingernails short; use a stiff, soapy brush to clean under your nails. |
| Wash your hands frequently and properly after contacting wastewater and before eating, drinking or smoking, use of smokeless tobacco products and at the end of work. |
| Wear appropriate gloves where necessary, especially when hands are chapped, cut or burned. |

Antimicrobial agents destroy pathogens by damaging cellular components. Antimicrobial agents can be used to disinfect the hands or hard surfaces such as lunch tables and laboratory counters. Automation, for example, automatic collection of wastewater samples and automatic cleaning of bar screens, reduces personnel contact with wastewater and pathogens. Cleanliness and consumption precautions and restrictions make use of good common sense, appropriate hygiene measures and personal protective equipment where appropriate.

| Chemical Agent | Action |
|---|---|
| Alcohols | Denature proteins |
| Alkalis (in soaps) | Denature proteins |
| Detergents and soaps | Lower surface tension of pathogens, making them susceptible to other chemical agents |
| Halogens | Oxidize cellular components |
| Heavy metals (in disinfectants) | Denature proteins |
| Oxidizing agents | Denature proteins |
| Phenol and phenolic compounds | Damage cell membrane and denature proteins |

Immediate first aid should be given to any cut or abrasion that occurs at a wastewater treatment facility. A physician should treat more serious injuries. Proper sampling techniques should prevent breakage and spillage. Sample bottles should have a wide mouth opening and, whenever possible, should be plastic. If glass containers are required, the glass should be coated with plastic. Lids for bottles should be tight fitting. Bottles and lids should be cleaned after each use with squirt bottles and paper towels. Carriers for sample bottles should be compartmentalized to prevent breakage, and sampling stations should be hosed down to wash away pathogens that may be present due to spillage or leaking bottles.

Protective clothing consists of uniforms, shoes or boots, masks, gloves and goggles. Protective clothing remains at the wastewater treatment facility and prevents wastewater personnel from bringing pathogens home. Protective clothing should be washed, dried and stored at the wastewater treatment plant or cleaned professionally. Separate lockers should be provided for work clothes and street clothes.

| Clothing | Action or Item |
|---|---|
| Gloves | Wear appropriate gloves at each work site; elbow-length gloves may be necessary; never submerge top of glove; wash or dispose of gloves after use; wash hands immediately after work when gloves cannot be used. |
| Goggles | Protect eyes from pathogens in aerosols and dust; wash goggles after use. |
| Masks | Prevents inhalation of pathogens in aerosols and dust; ensure proper fit of masks; wash or dispose of masks |

| | |
|---|---|
| | as directed after use. |
| Uniforms | Leave uniforms at work; use separate lockers for work and street clothing; wash work uniforms at work or use professional service; use bleach on heavily soiled uniforms |

Safety records should be maintained for all wastewater personnel. The records should include information addressing accidents, immunobiologicals, major and minor illnesses and training.

Training should provide information regarding the hazards of pathogens found in wastewater, areas of significant exposure to pathogens, and the use of appropriate hygiene measures and protective equipment. Training should also review significant pathogens that are present in wastewater, their transmission and portals of entry, clinical symptoms of gastrointestinal and respiratory tract infection and available immunobiologicals.

Proper ventilation helps to reduce the risk of infection from pathogenic agents, including allergens and toxins, by reducing their numbers. Pathogenic agents are present in higher concentration in poorly ventilated areas as compared with outside areas and properly ventilated areas. Areas of poor ventilation usually are bar screens, grit chambers, lift stations, sludge dewatering facilities, wet wells and manholes.

# Hydrogen Sulfide $H_2S$

**Hydrogen Sulfide:**

- Is explosive
- Most common odorant
- Produced by anaerobic bacteria
- Gaseous form of sulfuric acid ($H_2SO_4$)
- Specific gravity of 1.19
- More persistent gas
- Odor recognition at **10 PPB**

**Physiological effect of $H_2S$ on humans**

| Less than 100 PPM | Greater than 100 PPM | Greater than 500 PPM |
|---|---|---|
| Eye and nose irritation | Destroys sense of smell | Brainstem toxicity |
| Cough | Confusion | Heart problems |
| Headache | Vomiting | Seizure |
| Bronchial problems | Loss of consciousness | No treatment |
| | | **DEATH** in a single breath |

# Ammonia Gas $NH_3$

Gaseous ammonia effects at various concentrations are as follows:

| Effects of exposure | gas in ppm/mg/L |
|---|---|
| Time-weighted average | 25 ppm or less |
| Detectable odor; unlikely to experience adverse effects | 25-50 ppm |
| Mild eye, nose and throat irritation | 50-100 ppm |
| Moderate eye irritation; no long-term problems | 140 ppm |
| Moderate throat irritation | 400 ppm |
| Immediately dangerous to life and health | 500 ppm |
| Immediate eye injury | 700 ppm |
| Directly caustic to airway | 1000 ppm |
| Laryngospasm | 1700 ppm |
| **Fatality (after half-hour exposure)** | 2500 ppm |
| Sloughing and necrosis of airway mucosa, chest pain, pulmonary edema and bronchospasm | 2500-6500 ppm |
| **Rapidly fatal exposure** | 5000 ppm |

# Carbon Dioxide $CO_2$

- At 1 percent concentration of carbon dioxide $CO_2$ (10,000 parts per million or ppm) and under continuous exposure at that level, such as in an auditorium filled with occupants and poor fresh air ventilation, some occupants are likely to feel drowsy.

- The concentration of carbon dioxide must be over about 2 percent (20,000 ppm) before most people are aware of its presence unless the odor of an associated material (auto exhaust or fermenting yeast, for instance) is present at lower concentrations.

- Above 2 percent, carbon dioxide may cause a feeling of heaviness in the chest and/or more frequent and deeper respirations.

- If exposure continues at that level for several hours, minimal "acidosis" (an acid condition of the blood) may occur, but more frequently is absent.

- **Breathing rate** doubles at 3 percent $CO_2$ and is four times the normal rate at 5 percent $CO_2$.

- **Toxic levels of carbon dioxide:** at levels above 5 percent, concentration $CO_2$ is directly toxic. [At lower levels, we may be seeing effects of a reduction in the relative amount of oxygen rather than direct toxicity of $CO_2$.]

Symptoms of high or prolonged exposure to carbon dioxide include:

- Headache,
- Increased heart rate,
- Dizziness, fatigue,
- Rapid breathing,
- Visual and hearing dysfunctions and
- Exposure to higher levels may cause unconsciousness or death within minutes of exposure.

## Carbon Monoxide   CO

The acute effects produced by carbon monoxide in relation to ambient concentration in parts per million are listed below:

| **Concentration** | **Symptoms** |
|---|---|
| 35 ppm (0.0035%) | Headache and dizziness within six to eight hours of constant exposure |
| 100 ppm (0.01%) | Slight headache in two to three hours |
| 200 ppm (0.02%) | Slight headache within two to three hours; loss of judgment |
| 400 ppm (0.04%) | Frontal headache within one to two hours |
| 800 ppm (0.08%) | Dizziness, nausea and convulsions within 45 min; |
| 1,600 ppm (0.16%) | Headache, tachycardia, dizziness and nausea within 20 min; death in less than 2 hours |
| 3,200 ppm (0.32%) | Headache, dizziness and nausea in five to ten minutes. Death within 30 minutes. |
| 6,400 ppm (0.64%) | Headache and dizziness in one to two minutes. Convulsions, respiratory arrest and death in less than 20 minutes. |
| 12,800 ppm (1.28%) | **Unconsciousness after 2-3 breaths. Death in less than three minutes**. |

# Chlorine $CL_2$

### Physiological Effects of Breathing Air Chlorine Mixtures

| Effects of exposure | $CL_2$ gas in ppm/mg/L |
|---|---|
| Slight symptoms after several hrs of exposure | 1 ppm |
| Irritates throat | 10-15 ppm |
| Causes coughing | 30 ppm |
| Dangerous in 30 minutes | 40-60 ppm |
| **Fatal in a few breaths** | 1000 ppm |

### Chlorination Safety Precautions & Facts

- If you have a leak in a cylinder, rotate the leak so gas and not liquid is escaping.
- One volume of liquid chlorine yields approximately 450 volumes of vapor.
- Never throw a leaking chlorine cylinder into water or hose it down. This will increase the size of the leak and worsen the situation.
- Use new lead gaskets when installing chlorine cylinders.
- Turn the chlorine valve on and right back off, test for leaks.
- Never open the cylinder valve more than one turn.

# Methane $CH_4$

- Is highly flammable and may form explosive mixtures with air.
- The explosive range of methane is 5-15%
- Methane is violently reactive with oxidizers, halogens and some halogen-containing compounds.
- Methane is also an asphyxiant and may displace oxygen in an enclosed space.

### Excavation hazards

Trench Shoring:

- All work in an excavation must be supervised by a qualified person.
- Remove hazards to employees, trees, boulders, poles, etc.
- Inspect excavation after rain, freeze/thaw or anytime you suspect a problem.
- Shoring or step-back any trench over 5 ft. deep.

- Spoil pile: move spoil pile far enough away so it won't fall back in the hole. At least 2 ft. away on one side only, for excavations over 5 ft.
- Use a ladder for access for trenches 4 ft. + every 25 ft. is required, don't climb on shoring.
- Don't jump across trenches. Install a crossing.
- Don't excavate under an existing structure's foundation without shoring bracing or underpinning.
- Use no existing retaining walls or structure as a retaining wall for the excavation.
- Barricade or tape off all potentional hazardous areas.
- Use diversion ditches, dikes or other measures to keep water out of the excavations.
- Use additional bracing on the shoring if near a road, railroad or other sources of vibration or external load.

<u>Sloping and Benching</u>

- If no shoring is used, the side walls of the excavations should be sloped at ¾ horizontal to 1 vertical.
- Benching is used for deeper excavations, starting at 3.5 feet in depth the typical bench is 2 feet wide for each 2 feet of additional depth.

## INFLOW AND INFILTRATION

Inflow/Infiltration is a major concern with most collection systems. Inflow is the excess rainwater that enters the system very soon after the rain begins and can normally be traced to unsealed manholes and illegal connections, such as roof downspouts, parking lot and yard drains. Infiltration is the excess water that continues to enter the system for three or four days after the rain has stopped and is the result of groundwater seeping into the system through breaks in the line and unsealed pipe joints. Inflow is usually more controllable and more easily eliminated.

Construction requirements limit the loss of waste from (or entrance of ground water into) a sewer system to 200 gallons per inch diameter per mile per day. This limitation is inclusive of manholes, sewer lines and appurtenances. At least 30" of ground cover shall be provided for additional protection. As part of the construction, the integrity of a new system has to be verified by means of either the infiltration/exfiltration, or low-pressure air testing methods. An infiltration or exfiltration test shall be performed with a minimum positive head of two feet.

The infiltration test is generally preferred when the groundwater level is above the crown of the sewer. The upstream end of the section to be tested is plugged, and a flow-measuring device (weir, etc.) is installed in the manhole at the lower end. The rate of leakage can then be measured.

In the exfiltration test when groundwater levels are too low to use the infiltration test, both ends of the section of sewer to be tested, including a manhole at each end, are plugged, and all stoppers and plugs are braced or otherwise secured to resist the internal pressure resulting from the test. The section is then filled with water to a predetermined level above the crown of the sewer, and the rate of leakage is computed on the basis of the observed drop in water level over a reasonably long period of time or by metering the volume of water to be supplied to the system to maintain the original water level.

In the air pressure test, a section between manholes is plugged and the plugs secured to withstand the expected internal pressure. Air is then introduced at a pressure above the maximum pressure exerted by any groundwater that may be present outside the pipe. After the air is shut off, the time it takes the pressure in the pipe section to drop by a predesignated amount is determined. Manholes should be tested separately.

Sewer lines, when flowing full, should have a **mean velocity of not less than 2.0 fps (feet per second)** to reduce the possibility of solids deposition in the collection system. A mean velocity of 10.0 fps or more may cause serious damage to manholes. The velocity may be calculated using the following equation.

$$\frac{\text{Distance in feet}}{\text{Time in seconds}} = \text{Feet per second}$$

The numbers needed for the equation above may be obtained by measuring the distance between two manholes, in feet and then inserting a ping pong ball in the upstream manhole and measuring the amount of time, in minutes and seconds, it takes to reach the second manhole. Normally, this requires at least two people with two-way communication devices.

All well-run municipal public works department recognize the importance of having a preventive maintenance program for their sewers. Not only does it cut down on the number of customer service complaints, it reduces maintenance costs in the long term. A worthwhile maintenance program should include a good recordkeeping system, quick response to service requests, a cycle of regular televising of revolving parts of the sewer system each year, regular cleaning of the system and regular attention to corrosion protection against hydrogen sulfide. Regular wet and dry weather flow monitoring can be used to see problems emerging, so corrections can be programmed in advance. In conjunction with water metering, this can be used to detect water main leakage and help with that system's maintenance.

Inflow and Infiltration or Sewer System Evaluation Studies (SSES)_are performed to identify the specific causes and quantify the amounts of I/I entering the sewer system. This information allows the public works department to prescribe the most beneficial corrective actions and estimate their costs.

The techniques usually employed in the I/I or SSES study are:

- Flow monitoring,
- Interviews of maintenance personnel and review of repair records,
- Visual inspections of lines and manholes,
- Smoke and dye testing and
- Televising of the lines, usually with dyed water flooding of the surface.

All have their place in the investigation process, and information from the least expensive techniques should be analyzed before going on to televising of the lines. Usually an adequate diagnosis can be made based on appropriate application of the cheaper techniques plus televising of about 20 percent of the system. We will now consider each of the major investigative techniques and their applications.

**Flow monitoring**

Flow monitoring is the least costly investigative technique for the amount of information gained. Generally, one should start an investigation by monitoring flows throughout the system to identify which drainage basins have the most excess wet weather flows. Gravity sewer flows can be directly monitored. For force mains, you will have to calculate flows based on metering of pumping rates and times. Pressurized sewer cannot have I/I problems, but their flows may need to be known for the systemwide analysis.

To set up your monitoring locations, divide the system into drainage basins and locate the meters at the manholes where the drainage basin joins into a larger flow. If possible, establish drainage basins that have similar materials or age, even if this leads to big differences in flows among basins. The goal is to be able to determine from the flow data which basins have the most extraneous flow, and whether inflow or infiltration predominates. This will allow you to plan out the rest of your investigation more economically.

To determine how much I/I the system experiences in wet weather, first measure the dry weather flows. Check the measured dry weather flows by calculating what they should be, based on building occupancies and types of usage. If measured dry weather flows are significantly higher than calculated flows, there may be a cross connection with a potable or fire protection water line, a leak in one of these lines which is causing dry weather infiltration, an underground spring causing infiltration or a perched or permanently high water table. Groundwater wells at a few key locations will help you determine if this is the case.

Wet weather monitoring data should be graphed as flow versus time on top of a rainfall versus time graph for the same period. Inflow will show up as elevated flows starting relatively close to the start of rain and dropping off soon after the rain stops. Infiltration may not show up right away, but will continue steadily after the rain stops and until the ground or trench around the sewer is no longer saturated.

Also, compare the total wet weather flows to the dry weather flow to see the magnitude of the problem for the various drainage basins. This way you will know in which basins to concentrate your efforts. Basins with high inflow should be investigated further using smoke and dye testing. Basins where infiltration is the predominant cause can be investigated using joint testing, visual inspections, and televising. First, perform interviews and a record review.

The following "rules-of-thumb" may be used to determine a monitoring and evaluation strategy to adequately measure amount of inflow and infiltration in a sanitary sewer system. These parameters vary depending on the overall city or agency goals.

- One flow meter for every 30,000 – 50,000 feet of sanitary sewer pipe.
- The flow meter recording should be set at 15-minute intervals.
- Flow meter capable of measuring surcharges.
- One rain gauge for every 2-4 flow meters
- Minimum monitoring period – 45 days with 60 days being optimal.
- Measurement of between 6-8 separate rainfall events.
- The system should be monitored during a period of high seasonal groundwater.

**Interviews and record review**
Public works maintenance personnel and workers at the various industrial facilities should be interviewed to find out where the known trouble spots are. Information of particular use is:

- Where blockages usually occur.
- Where there is flooding or sewer backups in conjunction with storm events.
- Whether there are areas of the city that have buildings with downspouts going into the ground, but with no nearby storm sewers.
- Which areas have had major repair work.
- What is the quality of the drawings you are basing your work on?
- Should your first step be to have the field drawings corrected?

The record review should include sewer service requests, repair projects that have been completed or proposed, correspondence with regulators or the POTW about excess flows, internal facility plans and drawings of the storm and sanitary sewers.

**Visual inspections of lines and manholes**
A lot of infiltration and inflow enters the sewer through deteriorated manholes. Manhole defects are readily apparent upon visual inspection. The manhole can be physically entered if the steps are in good condition and confined space entry precautions are observed. The following are common sources of infiltration and inflow through manholes (all are exacerbated if ponding occurs over the manhole): holes in manhole covers, poor

fit between manhole cover and rim, cracks and holes in the pavement around the manhole rim, cracks or misalignment between bricks in the manhole, loss or absence of mortar between the bricks, cracks in the invert and gaps or misalignment of connecting pipes.

The lines can be visually inspected through the manhole, by either lamping the lines and looking up them while in the manhole or by using a remote halogen light and mirror while standing above the manhole.

An important word of caution: Remember that even while working over an open manhole, you must observe confined space precautions. Sewer gases can render you unconscious before you detect them with your unaided senses, and many people have been killed by falling unconscious into manholes. In addition, methane gas, common in sewers, is very explosive, so sparks and open flames must always be kept away from sewers or manholes.

House-to house inspections are simple inspections of the exterior and interior of a property or residence. Inspectors check for illegally connected roof, yard, driveway, basement and foundation drains, as well as sump pumps. Inspections usually take less than 10 minutes.

**Smoke and dye testing**
Smoke and dyed water testing can be used to identify inflow locations and cross connections, where inflow has been implicated as a problem in the results of the flow monitoring.

In smoke testing, a non-toxic "smoke bomb" is used to produce smoke. A blower is fitted over the top of the manhole for 15-20 minutes to purge the sewer of gases before the smoke is introduced. The pipes at the upstream and downstream manholes are blocked off to isolate a section of line. If there are any connections to the sewers, the smoke will travel up them. If there are any untrapped drains, the smoke will continue to travel until it gets to atmosphere.

Smoke testing is an effective way to detect storm connections to the sanitary sewer. Roof drains and catch basins connected to the smoked line will emit smoke. If there are significant cracks or holes in the pipeline, the smoke will come up through the ground above the pipe. To detect this, the smoke testing must be done during dry weather periods. Smoke testing is inexpensive. Sewer maintenance crews can easily carry it out. The engineer or technician in charge of the investigation should be on hand during the smoke test to observe and interpret the results. Pictures are usually taken to include in the report. **Always inform the fire department and the nearby building occupants when you will be performing the testing, to prevent undue alarm.**

Dyed-water testing is like the reverse of smoke testing, in that dyed water is flooded on the surface or into potential sewer connections, and the nearest manhole is observed for signs of the dyed water. If the surface is flooded with dyed water and it gets into the pipe, it has entered through holes or cracks. If you suspect that a particular catch basin is connected to the sanitary sewer, you can dye running water from a hydrant or hose into the catch basin and look for it at the nearest downstream manhole. This is a very inexpensive technique and involves no equipment, just a bottle of dye and a water source.

**Cleaning and televising the lines**

Before lines are televised, they must be cleaned. This can be accomplished by pigging the lines, which is dragging a large rubber pig or plug through the lines, or jetting, which is sending a high pressure water jet through. Jets can also be used to pull a cable through the pipe, which will then be connected to the television camera to pull it through. While the lines are being cleaned, observe the debris that is removed. The contents of this debris will give you some indication of the condition of the sewer and the possible trouble sources. If there is grease, you may need to install or better maintain your grease traps. If there are roots, root intrusion may have caused cracks or joint separation. You may wish to regularly rod the lines or apply chemical root killers. If the removed debris includes dirt and pieces of broken pipe, you've probably got missing sections of pipe and may have to replace parts of the line.

Televising must be done during wet weather or dyed water flooding of the surface. Wet weather is most effective, because it will also show sources of inflow. As the camera is drawn through the sewer, the film will record exact locations (in stations) of water entering the pipe. An expert can determine by watching the tapes how much water is entering in each defect in gallons per minute. The tape can also show the structural condition of the line. Also look for signs of hydrogen sulfide induced corrosion.

Televising is an expensive investigation technique--about $2 per linear foot, plus the cost of light or heavy cleaning which will add about another $1/ft. While televising rigs can be purchased for about $100K, most facilities find that it is more cost effective to hire a local sewer service company when this work is needed.

**Analyzing the results**

Once you have identified the quantities and sources of infiltration and inflow to your system, you will need to prioritize the defects in order of importance. The highest priority for rehabilitation is to maintain the structural integrity of your sewer system. Your biggest investment is the hole through the ground. So, if your investigation reveals places where your sewer is failing structurally, either experiencing collapses or where collapses are imminent, use these prescribed methods if the investigation showed signs that this was causing deterioration of your system. The next priority is the exclusion of extraneous clear water.

A fairly simple cost-benefit analysis can be done to determine a cut-off point for fixing infiltration or inflow sources. First, determine the cost of transporting and treating a gallon of sewage in your system. Next, determine the costs for repairing the various defects. Divide the cost of the repair by the amount of I/I the fix would remove from the system. If this cost is less than the cost to transport and treat, it is cost-effective to do the repair, if this cost is higher, continue to allow the I/I from that source into the system.

There are some important exceptions to this simple analysis. You must also take into consideration why you are looking to get rid of the I/I in the first place. Are you violating your NPDES permit with hydraulic overloads? Is your sewer system under capacity for it's current demands. These issues could control your decision more than the economics.

For a system of average age and size, the following guidelines can be used to forecast the long-term costs that can be anticipated.

**Cost-estimating guideline**

Sewer System Evaluation Survey

- Flow Monitoring/Analysis $0.15 - $0.30/lf
- Physical Inspection $0.75 - $1.50/lf
- Cleaning/CCTV Inspection $1.50 - $3.00/lf
- Hydraulic Modeling $0.10 - $0.20/lf
- Plans and Specifications 5.0 - 8.0% of Const. Est
- Legal/Administration 1.0 - 3.0% of Const. Est

Construction

- Pipeline Rehab (8-12") $45.00 - $150.00/lf
- Manhole Rehabilitation $30.00 - $300.00/vf
- Point Repairs (5-10') $1,500 - $7,750/ea

The above cost-estimating guideline can vary depending on the size of the collection system and the actual rehabilitation requirements. Cost information is based on 2009 data.

**Removing I/I**

There are many methods and technologies that are available to remove and reduce I/I. Modern techniques allow for sewer lines to be inspected, cleaned and even replaced without traditional open cut excavation. By utilizing “Trenchless Technologies, rehabilitation and repair can often be performed without interruption of sewer service or traffic disruption. Specific techniques that are available for fixing Infiltration sources are listed below:

Sewer Lines

- Manhole-to-Manhole Lining:
- Cured-in-place
- Fold & Form
- Slip Lining

- Pipe Bursting
- Dig and Replace
- Spot Repairs - sectional cured in place liner
- Spot Repairs - dig and replace manholes
- Exterior Coating or Grouting
- Interior Lining
- Replacement
- Inflow Dish
- Raise or Replace MH Covers and Frames

Inflow can also be removed by a variety of techniques, but these usually require a direct disconnection of the sanitary sewer system from the inflow source. Below is a list of methods that may be used to remove inflow.

- Disconnect roof leaders, sump pumps, foundation drains, or other illegal or improper connection from the sanitary sewer system.
- Encourage the removal of private inflow sources through enforcement of state, local regulations or incentive programs.
- Raise manhole covers that are located in low areas where stormwater may pond.
- Divert stormwater that flows to manhole covers.

## MATH REVIEW PROBLEMS

### Class I

1. A new manhole is going in and you have to remove a circle of asphalt 35 feet in diameter. How many square feet are involved?

2. If the asphalt in the problem above is 8 inches thick, how many cubic feet of material must be removed?

3. A rectangular wet well is 12 ft x 24 ft. What is the surface area in $ft^2$ of this wet well?

4. If the wet well in the above-mentioned problem is 16 feet deep, what is the volume of the wet well in $ft^3$?

5. If the wet well in the above-mentioned problem is 16 feet deep, what is the volume of the wet well in gallons?

6. Manhole # 22 is 475 ft from manhole # 23. On the blueprint 1 inch = 100 ft. How long is the line on the blueprint?

7. The line on the blueprint is 7.5 inches long between manhole #33 and #34. Each inch is equal to 50 ft. How many feet are there between manholes #33 and #34?

8. How many gallons per day would a community of 17,425 people contribute to the collection system daily?

9. A sewer has failed and 61 feet of 12-inch pipe must be replaced. How many 10 foot sections will be required?

10. What is the capacity of a wet well if the pump, rated at 125 gpm, requires 1 hr. 4 min. to empty? Assume no inflow.

11. A 12 inch wide channel is running 8 inches deep at a velocity of 3 ft per second. What is the flow rate in gallons per minute?

**Class II**

**12.** What is the percent grade on a 2 feet rise in 300 feet?

**13.** To lay a new line you must dig a trench 5 feet deep, 3 feet wide and 475 ft long (assume vertical sidewalls). How many cubic feet of material must be excavated to complete this project?

**14.** Using the data from the previous problem, if you had an 8 cubic yard dump truck, how may loads would have to be moved to stockpile the excavated material?

**15.** An 18 feet deep lift station has a diameter of 12 feet. The influent flow causes the water level to rise 4.5 ft in 22 minutes. What is the influent flow rate in gpm?

**16.** A junction box is 12 feet wide and 18 feet long and the bottom tapers from 12 feet deep on one end to 15 feet deep on the other. What is the volume in gallons of the junction box?

**17.** A 25 feet deep lift station has a diameter of 20 feet. The influent flow causes the water level to rise 2 ft 9 inches in 42 minutes. What is the influent flow rate in gpm?

**18.** The elevation at the upper manhole is 436.7 ft. The elevation at the manhole 275 ft downstream is 430.4 ft. What is the slope?

**19.** The distance between manhole #345 and #346 is 395 ft of 14 inch pipe. The grade on the plans is 4% or 0.04. How much drop in feet of elevation will there be from #345 to #346?

**20.** The distance between manhole #645 and #646 is 455 ft of 8 inch PVC pipe. A dye packet was added to manhole #645 and 4 minutes 45 second later color was observed in manhole #646. What is the velocity of the wastewater?

**21.** A flow of 980 gpm is flowing through a 15 inch wide channel at a depth of 9 inches. What is the velocity of the flow?

**22.** The meter reading on lift station #76 on April 10 at 8 a.m. was 32,445,560 gallons. On April 17, at 8:00 a.m. the meter reading was 41,896,760 gallons. What is average daily flow through this lift station?

**23.** Using the data from the previous problem, if you were feeding 9 mg/L of chlorine for odor control, how many pounds of chlorine would be fed per day?

**24.** Using the data from the previous problem, if chlorine sells for $1.17 per pound, what is the monthly chemical bill for chlorine, given a 30 day month?

**25.** Average flow to a wastewater treatment plant is 0.9 MGD. On a wet weather flow day the flow rises to 3.3 MGD. What is the % inflow and infiltration?

**26.** The elevation of manhole #34 is 342.6 ft and the elevation of manhole #33 is 335.6 ft. They are 370 feet apart. What is the percent of slope?

**27.** The wet well of a pump station is 6 feet wide by 6 feet long. With one pump running and discharging 280 gpm, the wet well level was observed to rise 2 feet in 3 minutes 15 seconds. What was the rate of flow (gpm) into the wet well?

**28.** The average flow to your facility is 0.85 MGD. When you receive an inch of rain your flow increases to 3.1 MGD. What is the percent inflow and infiltration?

**29.** A new manhole has been installed 350 feet from an existing manhole. On a map with a scale of 1 inch equals 75 feet, how far would this new manhole be located from the existing manhole?

**30.** A 14 inch force main 4,500 feet long has a flow rate of 0.77 MGD. What is the detention time in the force main in hours?

**<u>Class III</u>**

**31.** The invert elevation of a manhole is 422.3 ft. If the invert at the next down stream manhole is 300 ft away at a $0.033^0$ slope, what will the invert elevation (IE) be?

**32.** The elevation at the invert of manhole #567 is 737.8 ft. The next manhole #568 is 410 ft downstream with an invert elevation of 729.4. What is the percent grade of this run of pipe?

**33.** Two 12.5 HP pumps run for 7.75 hours per day each. One pump is 85% efficient and the other pump is 75% efficient. How many kilowatt hours were used in a 24 hr day?

**34.** Using the data from the previous problem, at $0.14 per kW hr, what is the 30 day electrical cost to operate this lift station?

**35.** On a wet weather day the flow into a 35 ft. diameter lift station has just activated the lag pump and only one pump appears to be in operation. The water level is rising at a rate of 1 foot every 2 mins. 45 sec. If the elevation of the lag pump switch is 452.8 ft and the manhole will overflow to the street at an elevation of 466.7 feet, how long do you have to repair or replace the defective pump?

**36.** A lift station with two 12.5 HP submersible pumps operates on an alternating cycle with pump #1 running 6.7 hrs and pump #2 running 6.9 hrs. These pumps have an efficiency average of 87.2%. At $0.11 per kW hr, what will it cost to operate the lift stations for 30 day month?

**37.** A lift station wet well is 14 ft in diameter and 22 ft deep. At a depth of 8 ft 4 in, how many gallons of wastewater are in this wet well?

**38.** What concentration of chlorine, in mg/L, is applied to a flow of 3.5 MGD if the total weight of 100% available chlorine used was 350 pounds?

**39.** A sewer line is to be filled with a root control solution containing 75 mg/L of a specific chemical. How much chemical in pounds would be needed for a 265 feet long section of 12-inch line?

**<u>Class IV</u>**

**40.** A 40 HP pump runs for 18 hrs per day and is 85% efficient. How many kilowatt hours were used in a 24 hr day?

**41.** Using the data from the problem above and one kilowatt hour cost $0.13; what would the total electric cost be to operate this lift station for 1 year?

**42.** A 24 inch force main is to be laid 3,675 ft from lift station #12 to the wastewater plant at an in-place cost of $202.00 per foot.

**A.** What is the total cost of this project?
**B.** If the labor cost was 13.5% of the total cost, what is the labor cost?
**C.** What would the excavation cost be if it was 61.2% of the total?
**D.** The material cost is what percentage of the total project cost?

**43.** You want to check the flow rate of a pump in a lift station rated at 250 gpm to determine its efficiency as compared to its rated capacity. The lift station has a diameter of 10 feet and a depth of 25 feet. The influent flow to the lift station rises, with no pump running, at a rate of 8 feet in 10 minutes and with the pump running the rise rate is 5 feet in 10 minutes

**A**. What is the influent rate in gpm?
**B**. What is the rise rate with a pump running in gpm?
**C**. What is the pump rate in gpm?
**D**. How efficient is this pump in %?

**44.** A town has two main lift stations, 25 ft in diameter and 40 ft deep. Pump station #1 has a total of three 1,000 gpm pumps, two that alternate with the third as a back up. The two alternating pumps work at 91% efficiency. In pump station #2 there is the same set up except the pumps are 1,250 gpm that operate at 89.5% efficiency. Both of these stations feed the main in-plant station with the total flow to the treatment plant.

**A.** If station #1 operated for a total of 18.4 hrs how many GPD are pumped to the in-plant station?
**B.** If station #2 operated for 21.6 hrs how many GPD will it pump to the in-plant station?
**C.** What is the total flow to this plant in MGD?

**45.** Using the data provided, what is the daily average flow rate from this lift station?

Flow meter readings:

| | | |
|---|---|---|
| Monday | March 20 | 223,234,445 gal |
| Monday | March 27 | 243,879,629 gal |

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**Why do utilities, excavators, contractors and the public have to call Kentucky811 prior to disturbing the earth?**

The Kentucky Dig Law (KRS 367.4901 to KRS 367.4917) has been in affect since 1994. The law requires all persons excavating to call at least two full business days before digging, and no more than 10 business days prior to digging. The act in its entirety can be viewed at the following Web site: www.kentucky811.org.